NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

ENERGY CHANGE DETECTION TO ASSIST IN TACTICAL INTELLIGENCE PRODUCTION

by

Derek A. Filipe

June 2009

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13. ABSTRACT (maximum 200 words)

Currently, signals intelligence (SIGINT) analysts are constantly overwhelmed by the amount of data they ingest. A relatively new technology, known as Energy Change Detection (ECD), was fashioned in order to alleviate a portion of the "background noise," or signals of non-interest to the SIGINT analyst. ECD has been tested and its operational capability verified and validated by senior analysts. With the current organizational structure within which ECD resides, its utility to the tactical user is limited. This limitation affects both the timeliness of intelligence production and volume of users it can accommodate. An analytical model was devised to determine the sources of latency in response to a request for information (RFI). Various obstacles are highlighted and a revised operating procedure was modeled. This thesis analyzes four aspects of an organization (task, technology, structure, and actors) and proposes a change in ECD implementation to affect the production of tactical intelligence. The intent of the revision, along with providing ECD to a tactical intelligence cell, is to allow the tactical commander to make more effective decisions with respect to the employment and deployment of forces, types of forces (kinetic versus non-kinetic) to employ, and maximizing the efficiency of organic intelligence collection assets. The organizational revision, coupled with required analyst training, allows information to be pushed to a tactical intelligence cell and commander within a window of six hours from collection of the signal. This window allows for the production of actionable intelligence, increases the efficiency of SIGINT analysts, and potentially drives tactical operations.

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ENERGY CHANGE DETECTION TO ASSIST IN TACTICAL INTELLIGENCE PRODUCTION

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Captain, United States Marine Corps
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Submitted in partial fulfillment of the
requirements for the degrees of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY (COMMAND, CONTROL, AND COMMUNICATIONS)

and

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ABSTRACT

Currently, signals intelligence (SIGINT) analysts are constantly overwhelmed by the amount of data they ingest. A relatively new technology, known as Energy Change Detection (ECD), was fashioned in order to alleviate a portion of the "background noise," or signals not of interest to the SIGINT analyst. ECD has been tested and its operational capability verified and validated by senior analysts. With the current organizational structure within which ECD resides, its utility to the tactical user is limited. This limitation affects both the timeliness of intelligence production and volume of users it can accommodate. An analytical model was devised to determine the sources of latency in response to a request for information (RFI). Various obstacles are highlighted and a revised operating procedure was modeled. This thesis analyzes four aspects of an organization (task, technology, structure, and actors) and proposes a change in ECD implementation to affect the production of tactical intelligence. The intent of the revision, along with providing ECD to a tactical intelligence cell, is to allow the tactical commander to make more effective decisions with respect to the employment and deployment of forces, types of forces (kinetic versus non-kinetic) to employ, and maximizing the efficiency of organic intelligence collection assets. The organizational revision, coupled with required analyst training, allows information to be pushed to a tactical intelligence cell and commander within a window of six hours from collection of the signal. This window allows for the production of actionable intelligence, increases the efficiency of SIGINT analysts, and potentially drives tactical operations.

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TABLE OF CONTENTS

LIST OF FIGURES

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LIST OF TABLES

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Professors Karl Pfeiffer and Daniel Bursch enabled me to pursue this topic and aided me whenever I needed help. They were always available and/or altered their schedule to be available. Their leadership was an inspiration to me as I reintegrate myself into the operational forces.

IN LOVING MEMORY,
MAY THE PEACE OF THE LORD BE WITH YOU

CAPTAIN JUSTIN PETERSON, USMC
AL ANBAR PROVINCE, IRAQ
1 OCTOBER 2006

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I. INTRODUCTION

A. MOTIVATION

> *The man who will go where his colors go, without asking, who will fight a phantom foe in the jungle and mountain range, without counting, and who will suffer and die in the midst of incredible hardship, without complaint, is still what he has always been, from Imperial Rome to sceptered Britain to democratic America. He is the stuff of which legions are made…His pride is in his colors and his regiment, his training hard and thorough and coldly realistic, to fit him for what he must face…and his obedience is to his orders. He has been called United States Marine.*
>
> *- T. R. Fehrenback, This Kind of War*

Almost seven and a half years into the Global War on Terror (GWOT), an increasingly heavy burden has been placed on the intelligence community (IC) to provide timely and actionable intelligence to the tactical user. Still, in 2009, too many times on the battlefields of Iraq and Afghanistan have there been U.S. or Coalition casualties, which could have been avoided if the correct intelligence was "pushed down" to the appropriate tactical commander. There have been too many instances of useful intelligence reaching a tactical unit 24 or 72 hours late.

The motivation behind this thesis is to provide more timely and actionable intelligence to tactical units worldwide by altering the organization of technology, personnel, and specific databases. The particular data in question will be processed through a relatively new technology (referred to throughout the thesis as "the process" or Energy Change Detection) focused on energy signatures of multiple types. This processed information will allow tactical users to focus and integrate organic intelligence collection assets, Civil Affairs Groups (CAGs), human intelligence (HUMINT) personnel, Psychological Operations Groups (PSYOPS), reconnaissance units, and/or other operational units in order to successfully complete the commander's mission.

B. THESIS OBJECTIVE

The overall goal of this thesis is the optimization of a classic sensor-to-shooter information flow model. The main objectives are outlined below:

- Analyze and model the current process of energy change detection (ECD) once a request for information (RFI) is sent to the queue.
- Determine areas within the current process where optimization is possible and mandatory in order to provide tactical intelligence.
- Develop a model of a proposed process capable of providing intelligence to conduct tactical operations in a timely manner.
- Suggest an operating tactical unit who would greatly benefit from having ECD as one of its capabilities.
- Demonstrate scenarios where ECD would be useful.

C. OVERVIEW OF EXPERIMENTAL PLAN

ECD will allow SIGINT analysts and military commanders alike to focus their assets on the mission to maximize effectiveness. According to the *Code of Best Practices for Experimentation* (COBP), discovery experiments "… may involve pure models and computer simulations to place the new concept in the context of other factors, or human-in-the-loop experiments to learn how people relate to the innovation and choose to employ it" (Alberts and Hayes, 2002). ECD has passed all initial experimentation, verification, and validation[1] and is being utilized operationally on a small scale.

The COBP states:

> Even when an initial discovery experiment is successful in suggesting military utility and some way of employing the innovation, more research and discovery experimentation will usually be required to validate the initial finding, to refine the employment concepts, or to determine the conditions under which the innovation is most likely to provide significant payoff. (Alberts and Hayes, 2002)

[1] Details of all experimentation, verification, and validation are classified.

A mature operating procedure does not exist for this technology yet. Ideally, as a technology is being developed, a standard operating procedure is being developed concurrently. More commonly, a new technology is developed, proven useful, and *then* a decision on the correct implementation is discussed. This is the case with many new technologies; a way to employ a technology effectively has not been established, nor are the possible implications understood at the strategic, operational, or tactical levels of warfare. A mature operating procedure developed now while operational use is minimal, will maximize the effects on the decision-maker.

The hypothesis: If Energy Change Detection is provided to a tactical intelligence cell then the potential for more effective decision-making by the tactical commander exists, focusing the SIGINT analyst on signals of tactical interest and maximizing the effectiveness of organic intelligence collection assets. Figure 1 illustrates this hypothesis.

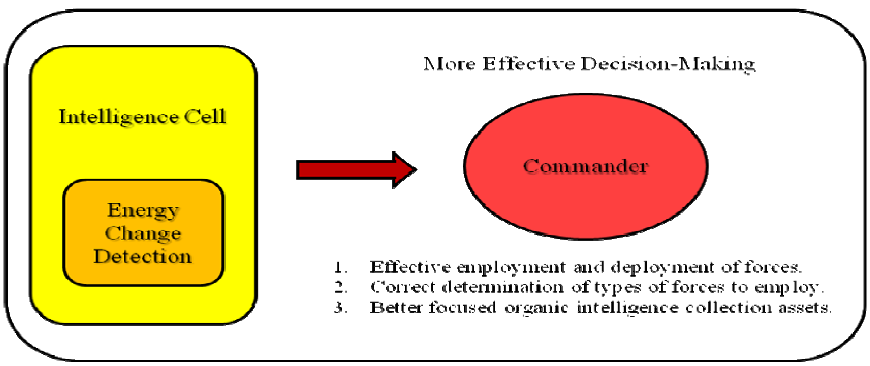

Figure 1. Illustration of Hypothesis.

Modeling and quantitative analysis will be used to test this hypothesis and show the utility of this technology at the tactical level. The current process will be analyzed. This analysis will then be validated by historical data (using all RFIs fulfilled in 2008) and verified by the analysts whom are current fulfilling all RFIs. A proposed solution will be modeled. A comparison of both models with respect to the time required to fulfill an RFI and the volume of RFIs handled per unit time will be made. Results of this comparison will either prove or disprove the hypothesis.

Following this analysis, ECD will be fielded to a tactical military unit to be tested in real-world operations. Upon completion of that unit's operational deployment, collaboration between intelligence analysts, commanders, and research personnel will occur. After action reports and lessons learned will be part of the operating procedure revision process. Once these revisions transpire, this technology will be acquired and fielded to all relative operating forces and on the proper information dissemination system or systems.

D. THESIS ORGANIZATION

The rest of this thesis is organized as follows. Chapter II provides background information on the new technology being proposed. Various sources of power are discussed and related to an asymmetrical adversary. It explains the difference between information and intelligence and relates these to sources of authority and clout. Also, Chapter II goes into detail on the implication on the adversary's OODA loop and the collection and storage systems form where the data is being derived from. A summary of Harlod Leavitt's theory, known as the Leavitt Diamond, is submitted along with an explanation on the employment of his theory to ECD. This research will analyze and model various portions of the current process once an RFI is submitted via a tactical user.

Chapter III describes the author's proposed solution to the latency of the current process. This proposed solution includes the organization of personnel and database management. Chapter III also describes the proposed tactical unit and its intelligence collection capabilities and limitations. A comparison of the process frameworks, as-is (Chapter II) and proposed (Chapter III), will be presented in Chapter IV. Also in this chapter is the quantitative analysis on the expected improvements to tactical operations with the proposed solution.

Chapter V concludes the thesis by summarizing the work, describing significant results to include the usefulness of the proposed process, and recommends future work necessary to validate the proposed process. Portions of this thesis are classified, and as such, not included in the unclassified version. Those portions are stored in the appropriate location.

II. BACKGROUND

A. INTRODUCTION

1. Sources of Information

The cliché "information is power" is as true today as it was at the onset of civilization. The sharing of information seems almost counterintuitive to human nature because of this fact, and may very well be the underlying reason why intelligence sharing amongst various organizations within the IC is a topic of concern. However, sources of information exist everywhere; and a lot of times they exists where people least expect. Many essays and papers, especially in today's world concerned with asymmetrical warfare[2], have been written (e.g., Arquilla and Ronfeldt, 1996) on the topic of information as a source of power.

The fact that information exists in non-physical matter (and more inclusively – all matter) is not a new concept. According to John Arquilla and David Ronfeldt (1996), "information, generally thought to be immaterial, is increasingly seen to be an essential part of all matter." While "power, long thought to be based mainly on material resources, is increasingly seen to be fundamentally immaterial, even metaphysical in nature." Arquilla and Ronfeldt view information in three views. Two views:

> . . . are widespread. The first considers information in terms of the inherent message, the second in terms of the medium of production, storage, transmission, and reception. The emerging third view transcends the former two; it speculates that information may be a physical property – as physical as mass and energy, and inherent in all matter. (1996)

This third view is the focus of ECD. Considering information a physical element and present in all matter is a powerful concept. More powerful is the concept of information residing in all energy.

Information is present throughout the entire electromagnetic (EM) spectrum. Figure 1 is a typical illustration of the EM spectrum with some of common bands labeled.

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[2] In order to scope this thesis, the term "asymmetrical adversary" is used interchangeably with "insurgent" or "insurgency."

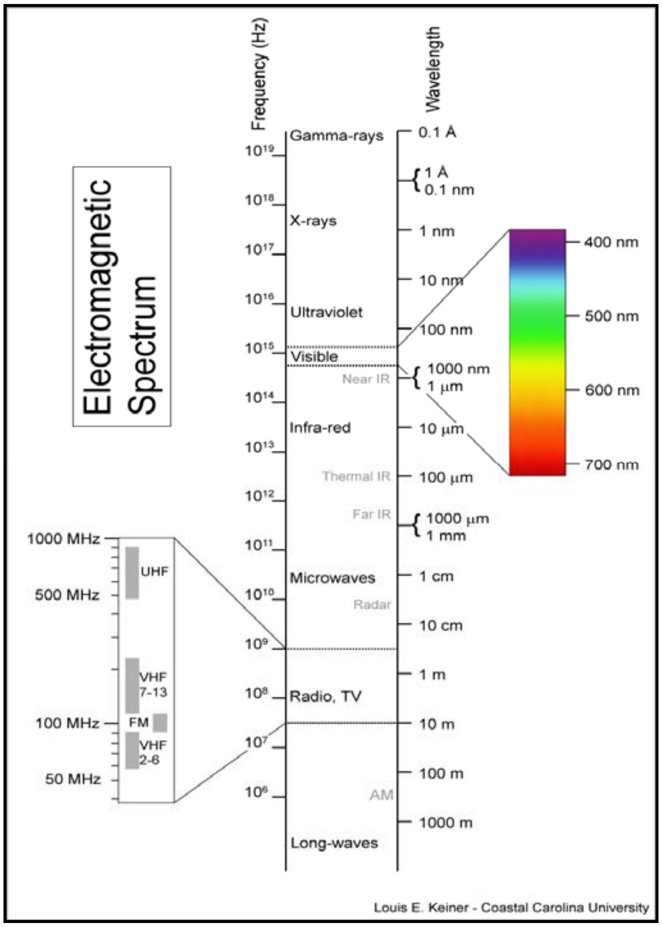

Figure 2. The Electromagnetic Spectrum (From Keiner, 2009).

As humans, we typically understand that information is contained within the visible and radio frequency portions of the spectrum. This is to say that what we hear and see supply our neurological sensors with signals that, when properly received, provide a human being information. We even understand the lack of energy in this spectrum range, i.e,. an image of a naval port *without* naval assets located there gives intelligence analysts a certain amount of information. A radio channel that is *not* transmitting as normal also provides a certain level of information. Information does not need to be contained within the energy (or waveform). The mere existence *or absence* of energy can provide an abundance of information. And with this information, useful intelligence may be derived.

2. Information as a Source of Power

Power is the great aphrodisiac.

- Henry Kissinger (New York Times, 1971)

If such a heavy emphasis is placed on identifying sources of information, then one can assume that information is a source of power. Otherwise, no one would care who had access to certain compartmented information. There are numerous definitions given to the term "power." Not only are there many definitions, but there are many disciplines, which can be referenced with "power." And within each discipline there are many distinct sources of "power."

Like most other entities, power can be defined in terms of quantitative and qualitative measurements. Quantitatively, power is the amount of work (or energy) done per unit time (Serway, 1996). Solar, electrical, and mechanical power are examples of power that can be classified as quantitative.

A qualitative assessment of power becomes more difficult. The DIME theory (Diplomatic, Information, Military, and Economic) is a well-known theory to categorize the source of power of state actors. Military and economic sources of power can be quantified easily (i.e., order-of-battle and gross domestic product analysis). Diplomacy and amount of *useful* information are characteristics much more difficult to quantify.

How does the United States match up versus a non-state actor in these categories? The answer is relatively simple to produce. Diplomacy is not applicable when dealing with non-state actors. Both militarily and economically, the U.S. dominates non-state actors. Then how come asymmetrical warfare is so costly for Americans? The answer lies in the informational realm. Table 1 below compares many factors of symmetrical and asymmetrical warfare. The "Key question" factor, under Information, is important in understanding information as a source of power. "*What* information to get" is the focus vice "*How* to get information" (NATO, 2002). As stated earlier, the U.S. does not have a capability gap in the *"How."* The gap resides in the "*What."*

Factor	Symmetrical, Conventional	Operations other than War
Mission/Operation		
Stability	Relatively stable	May be more dynamic
Focus	Enemy	No traditional opponent
Commitment	Common (military)	Uncertain (political/military)
Principles		
Unity	Of command	Of purpose
Decisionmaking	Hierarchical	Consensus
Operations	Surprise, secrecy	Transparency
Information		
Nature of the Problem	Known unknowns	Unknown unknowns
Key question	How to get information	What information to get
Focus	Enemy military	Military/political/economical/social factors
Situational Awareness	Common air-land-sea	Limited dissemination, more complex
Databases	Very large, well structured	Larger, less structured
Analysis		
Unit	Battalion level entity	More behavioural
Ease in integration	Relatively easy	Very difficult
Focus	Military (systems, organisations)	Political/military and societal
Approach	Traditional operation analysis	"Softer" analysis

Table 1. Factors of Symmetrical and Asymmetrical Warfare (From NATO, 2002).

It has been said by many military strategists, with respect to the GWOT, that "he who controls the people, controls the war." This statement is true in all the current conflicts the U.S. military is involved. The populace is controlled by information via many different mediums (i.e., television, telephone, newspaper, and the internet).

3. Information versus Intelligence

> Don't be buffaloed by experts and elites. Experts often possess more data than judgment. Elites can become so inbred that they produce hemophiliacs who bleed to death as soon as they are nicked by the real world.
>
> - General Colin Powell, USA (CJCS, 1992)

There are many instances in our everyday lives where the terms "information" and "intelligence" are used synonymously. In fact, they are two distinct concepts with separate definitions. Joint Publication (JP) 1-02 defines intelligence as:

1. The product resulting from the collection, processing, integration, analysis, evaluation, and interpretation of available information concerning foreign countries or areas.

2. Information and knowledge about an adversary obtained through observation, investigation, analysis, or understanding.

Even the Joint Publication's definition blurs the difference using the term information to define intelligence. Figure 3 from JP 2-01 demonstrates the joint military view of the transfer of information and intelligence to the decision maker.

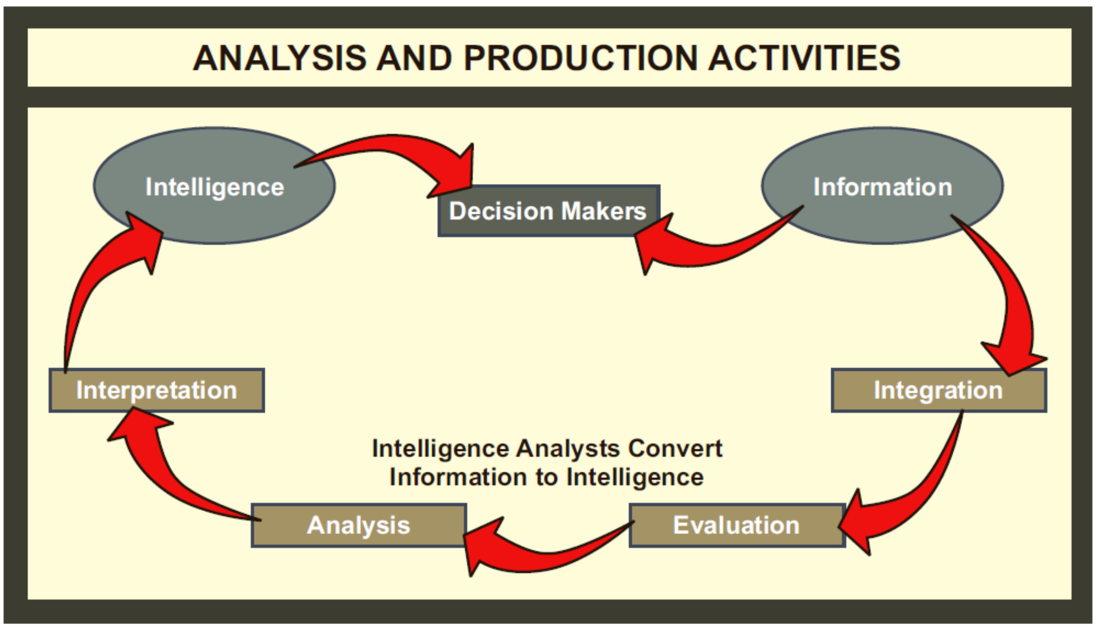

Figure 3. Analysis and Production Activities (From JP 2-01, III-34).

An explanation of the various levels of understanding is provided in the information pyramid analysis.

There are many information pyramids in academia, and most have three or four levels. The more complete versions differentiate between two types of intelligence: knowledge and wisdom. Referring to Arquilla and Ronfeldt's *In Athena's Camp*, the information described in a pyramid related to the concept of "Information as Message" where information is expressed as "an immaterial message or signal that contains meaningful (or at least recognizable) content and that can be transmitted from a sender to a receiver" (Arquilla and Ronfeldt, 1996). The information pyramid is visually portrayed in Figure 4.

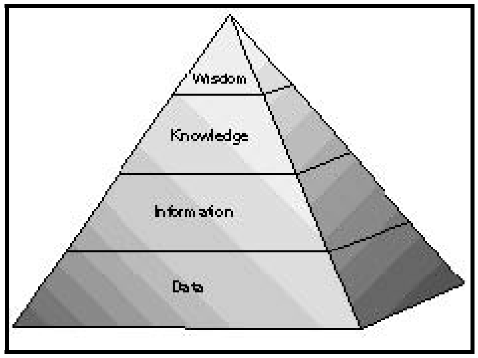

Figure 4. The Information Pyramid (From Arquilla and Ronfeldt, 1996).

The foundation of the pyramid is data. Data can come in many forms, i.e., digital cable in the form of 1s and 0s, recorded observation of rainfall, or facts listed in a Farmer's Almanac. The conversion of this raw data to information requires organization. Once the data is arranged in such a way that is humanly decodable, then the transformation is complete. A typical example of this is taking rows of data in a Microsoft Excel spreadsheet and creating a chart or graph based on the data. The processing and exploitation activities as defined by JP 2-01 are captured in Figure 5.

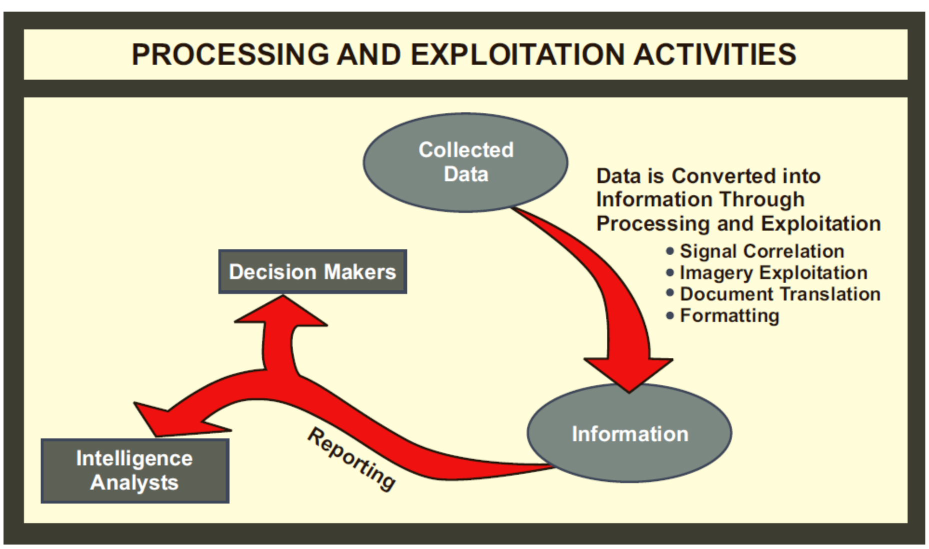

Figure 5. Processing and Exploitation Activities (From JP 2-01, III-29).

Intelligence is analyzed information. When dissecting intelligence into knowledge and wisdom, then knowledge is the analyzed information. Understanding what the information portrays is knowledge. A very important aspect of knowledge is that different people will have diverse levels of knowledge based on a certain set of information. The New York Stock Exchange trend analysis is an example of this. The same set of information may cause one investor to sell a stock and another to buy that same stock.

The distinction between the two investors resides in their individual levels of experience and intellect. Combining knowledge with experience and intellect generates the highest level of understanding; Wisdom. Only knowledge or intelligence products may be created. Wisdom is used in deciphering and analyzing the intelligence through ones individual experiences and level of intellect. The concept of levels of information can be confusing and frustrating if not understood correctly. The following scenario from Operation: IRAQI FREEDOM (OIF) is used as an example to take the reader through the four stages of information.

a. Data

Anytime an improved explosive device (IED) is found or detonated, a detailed description of the event is filed in a database. Data is gathered and consolidated from multiple sources in the database. Some properties of the event are date, time, location, unit, type of IED, type of detonation, type of explosives, found or cleared, and casualties. All of this information is stored in a database and able to be extracted via a query tool. The following table is an example of IED data taken from http://icasualties.org and is a list of all IED fatalities by month since commencement of OIF through February 2009:

Period	Fatalities
Jul-03	4
Aug-03	7
Sep-03	6
Oct-03	13
Nov-03	20
Dec-03	18
Jan-04	20
Feb-04	10
Mar-04	20
Apr-04	19
May-04	26
Jun-04	14
Jul-04	18
Aug-04	19
Sep-04	16
Oct-04	13
Nov-04	18
Dec-04	14
Jan-05	38
Feb-05	25
Mar-05	13
Apr-05	20
May-05	35
Jun-05	35
Jul-05	39
Aug-05	40
Sep-05	40
Oct-05	59
Nov-05	41
Dec-05	42
Jan-06	25
Feb-06	38
Mar-06	14
Apr-06	52
May-06	43
Jun-06	34
Jul-06	23
Aug-06	31
Sep-06	32
Oct-06	54
Nov-06	45
Dec-06	71
Jan-07	36
Feb-07	28
Mar-07	54
Apr-07	72
May-07	90
Jun-07	74
Jul-07	46
Aug-07	34
Sep-07	28
Oct-07	22
Nov-07	24
Dec-07	8
Jan-08	23
Feb-08	17
Mar-08	21
Apr-08	29
May-08	14
Jun-08	11
Jul-08	3
Aug-08	7
Sep-08	3
Oct-08	2
Nov-08	2
Dec-08	1
Jan-09	3
Feb-09	6
Total	1822

Table 2. IED Data (From http://icasualties.org).

It is difficult to visualize what the table is telling the reader because the data is not displayed in an easily recognizable format.

b. Information

Displaying data in a chart or graph is a typical way to convert data into information. Visualization allows a human to take days-, weeks-, months-, or years-worth of data and observe points of increase and decrease, levels of stability, and relative number of events compared to a similar time period. From the following table, an individual can deduce that May 2007 had the most IED activity to date in OIF. There are also other local maxima (January 2005, November 2005, and December 2007) and local minima (April 2006 and December 2008) that require further analysis.

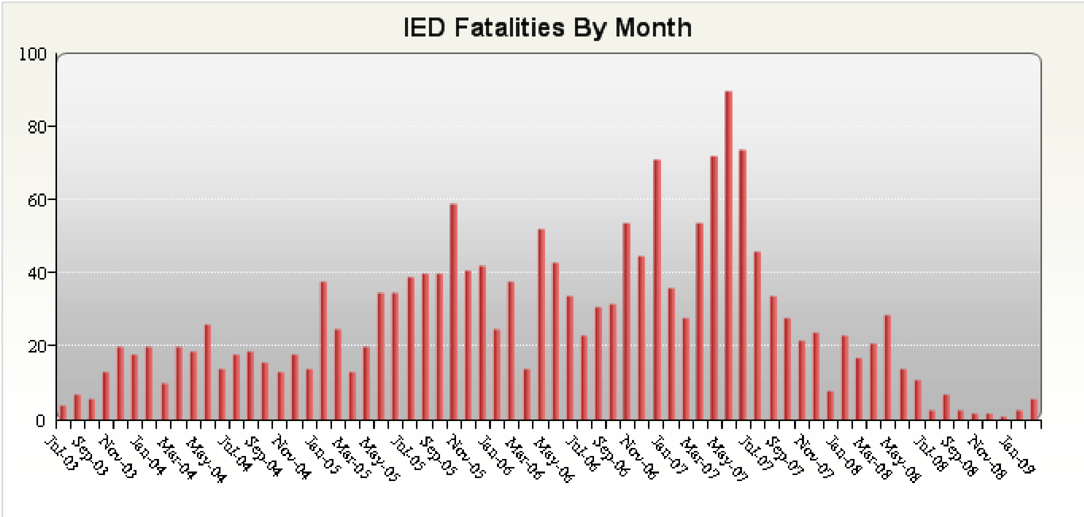

Table 3. IED Graph (From http://icasualties.org).

Sometimes, improper deductions are made based on a certain set of information. From the above table, it would be incorrect to infer that the drop-off in IED activity from May 2007 to the present is because the Iraqi Army has evolved into a self-sustaining organization able to defeat the insurgency. There are many other factors that must be included in an analysis of this magnitude. Carelessness in assumptions may lead to incorrect analysis of the data and information.

c. Knowledge (Intelligence)

Analyzed information is commonly referred to as intelligence. As stated above, intelligence will be broken into two sections; knowledge and wisdom. Combining the information provided above with other sources of information (i.e., a human intelligence report from the same time frame) is critical to converting the information to intelligence. Table 3 above does not give much insight into the various population centers throughout Iraq. The following six figures from http://icasualties.org show the IED events by geographic location and year.

An example of knowledge gained from the above information example is the heavy concentration of IED events in Al Anbar up through 2006 and Baghdad up to 2007. A decline in IED events after 2007 suggests either another form of attack is becoming the primary insurgent tactic or the increase in number of U.S. Military

Servicemen, known as “The Surge,” is helping to turn the tides. This information may be used to deploy forces where IED events occur most frequently. One can also see the trend of increasing IED events after 2006 to other regions of the country. Providing the analyst a better understanding of the situation is possible by combining this knowledge with other sources of intelligence, such as human intelligence or SIGINT. Intelligence must be fused from multiple sources to reach its full potential.

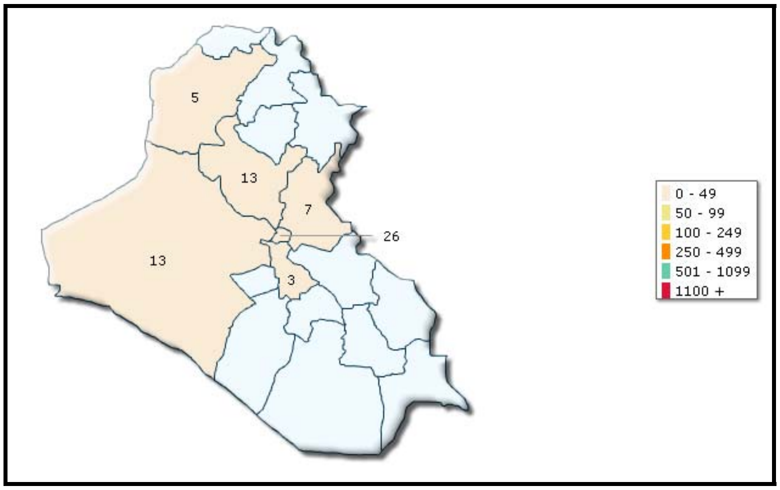

Figure 6. IED Fatalities in 2003 (From http://icasualties.org).

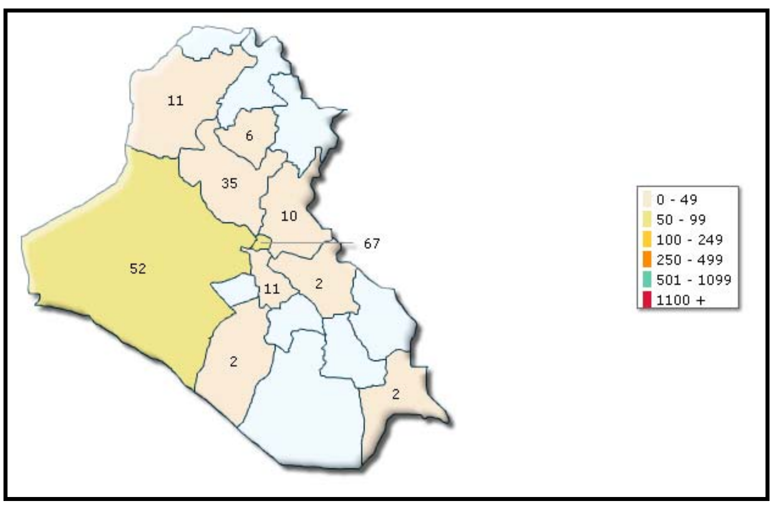

Figure 7. IED Fatalities in 2004 (From http://icasualties.org).

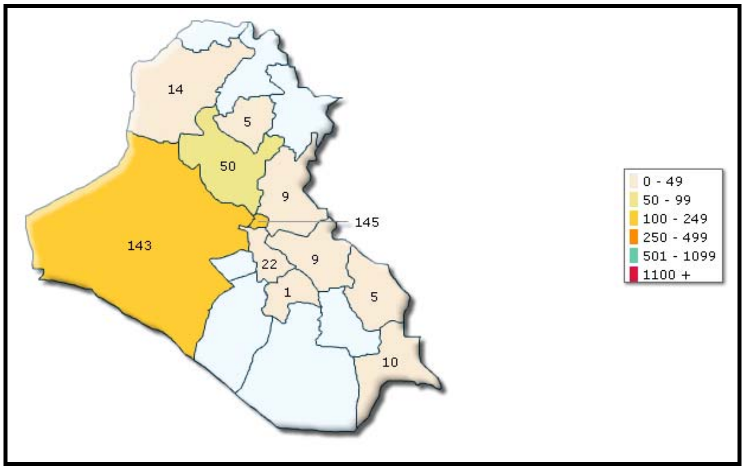

Figure 8. IED Fatalities in 2005 (From http://icasualties.org).

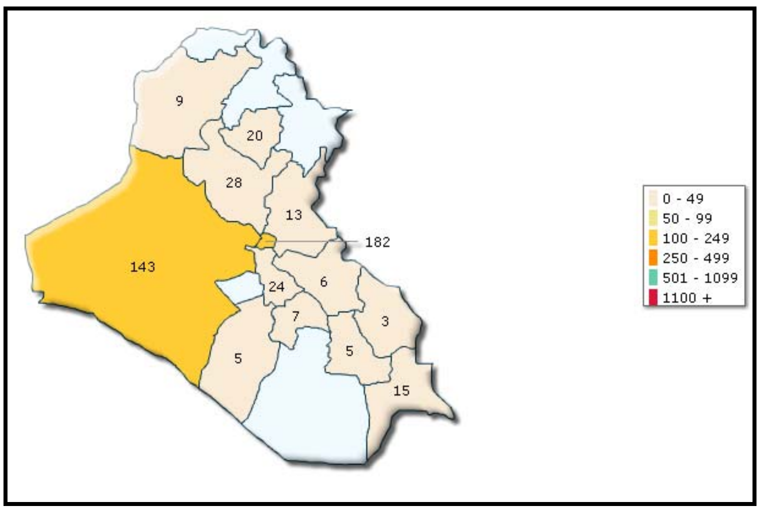

Figure 9. IED Fatalities in 2006 (From http://icasualties.org).

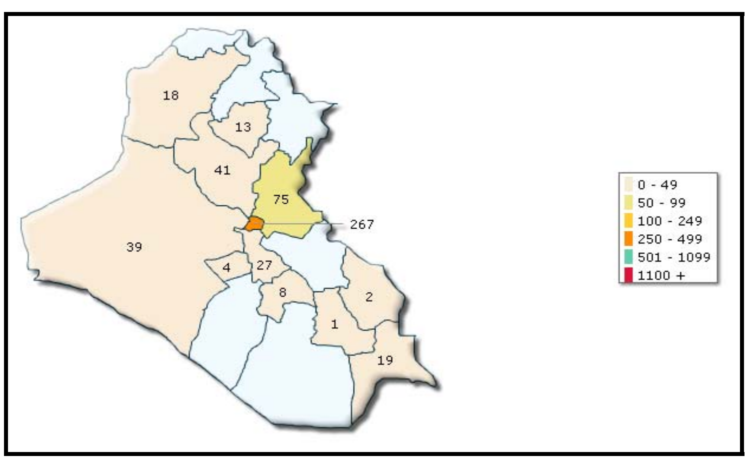

Figure 10. IED Fatalities in 2007 (From http://icasualties.org).

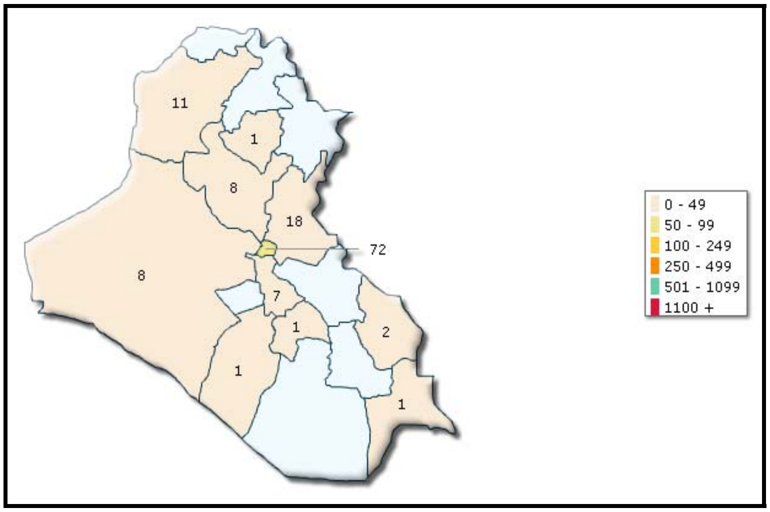

Figure 11. IED Fatalities in 2008 (From http://icasualties.org).

Questions an analyst will ask him/herself include "*Why* is there a spike in activity in this year?" or "*How* were X number of IEDS detonated in area A vice area B?" Coalition operations, religious holidays or events, or regional politics may be the answer or provide more information to arrive at the correct answer. A limited background in the topic under analysis may lead to an incorrect analysis of the information. This will produce an intelligence report that lacks credibility and is rendered useless in the eyes of the IC and a tactical commander. A tactical commander may have too much faith in the analysis conducted, forming a situation where tactical operations are conducted on faulty intelligence.

d. Wisdom

Knowledge will vary from person to person, as will wisdom. Wisdom is an individual's ability to apply analyzed information to personal experiences in the field of study along with an in-depth intellect in the subject area. Wisdom requires the accumulation of time with respect to a given subject area. An analyst in Washington D.C. with no operational experience in Iraq will interpret and analyze information and intelligence differently than an analyst who is currently on their fourth deployment in support of OIF.

With the above Iraq example, an in-depth understanding of the main supply routes, coalition activity, and local religious or political agendas may persuade the analyst to believe “The Surge” was the reason for recent success. Someone with operational experience would attribute the recent success to the Marines and soldiers embedded with Iraqi Security Forces. Their mission to advise, mentor, and train the ISF laid the foundation for “The Surge” to be effective. This wisdom would not be possible without the operational experience necessary to understand the difference between Iraqi and Western culture.

e. Impact of ECD on the Information Pyramid

ECD is a new method of signals information that displays relative information and attempts to mask the extraneous activity. ECD by itself does not produce intelligence. This new visual representation of emitters will permit SIGINT analysts to not only focus on signals of interest, but also a trend analysis on signal patterns in a specific area of operations for a given time interval. Focusing on signals of interest allocates more of the analyst’s time to useful work, not wasting time on signals which are not important to the mission. Conducting a trend analysis on the visualization of signal patterns will provide the tactical commander an insight into the selection and utilization of forces. Both provide intelligence to the tactical commander that will aid in mission success.

4. OODA Loop

> Without our genetic heritage, cultural traditions, and previous experiences, we do not possess the implicit repertoire of psychological skills shaped by environments and changes that have been previously experienced.
>
> - Colonel John Boyd, USAF (The Essence of Winning & Losing, 1995)

Colonel John Boyd, USAF, developed the OODA (Observe–Orient–Decide–Act) loop originally to describe the decision cycle a fighter pilot constantly undergoes in aerial combat. Because of the speed at which these engagements occur, the pilot must maintain fluid, speedy cycle. Colonel Boyd showed many instances throughout history where the

OODA loop framework could describe all levels of warfare. He also "saw it deeply relevant to any kind of competitive environment: business, politics, sports, even the struggle of organisms to survive" (Greene, 2007). Figure 12 is a simplistic illustration of Colonel Boyd's conceptual loop and Figure 13 is a more detailed drawing.

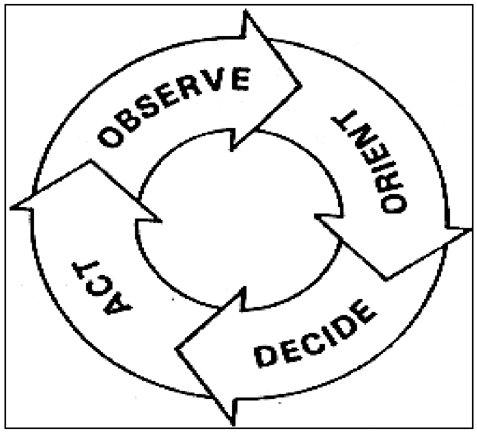

Figure 12. The Simplistic OODA Loop (From Greene, 2007).

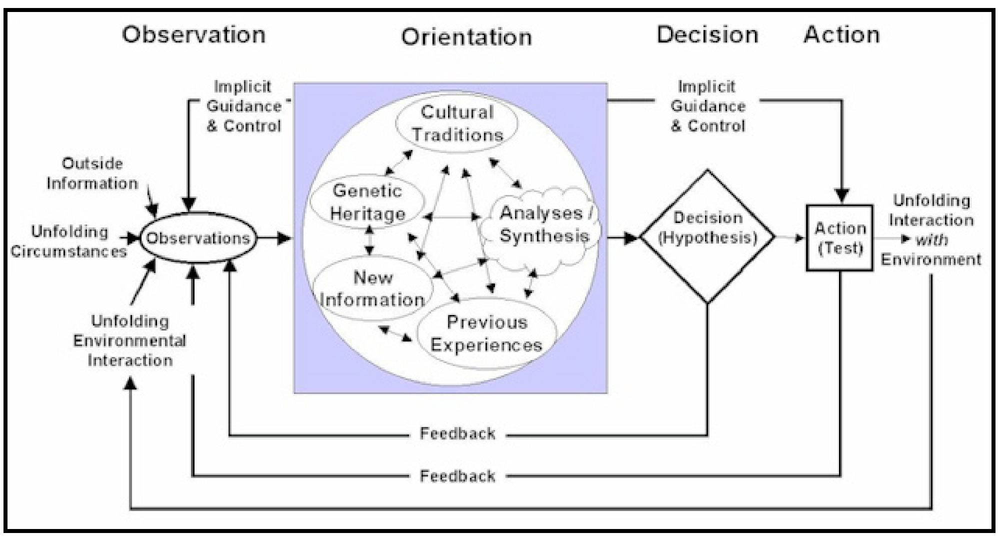

Figure 13. A Detailed OODA Loop (From Greene, 2007).

Observations are derived from all senses at the commander's disposal. The observations portray a visual image to the commander of the current situation, known as "ground truth," allowing that commander to orient to a given situation based on past observations. A decision is formed and then acted upon. This action (and decision) creates new observations which then begin the cycle anew. Greene describes the main elements as (Greene, 2007):

- *Observations* originate from human sources as well as from data, test results, intelligence sources, and models about a situation.
- The goal of *orientation* is to make sense of the observations.
- Making a *decision* is not a single action, but is a process of repeatedly *deciding what to do next—observe* more information, do further *orientation*, or take *action*.
- The proof of the success of the OODA loop is in the success of the *action* taken.

An OODA loop is inherent in every decision-maker. The goal for a commander is to make their OODA loop run as efficiently and quickly as possible. In military conflict, it is imperative to force your adversary to react to your operations. This is accomplished by allowing your OODA loop to operate inside your adversary's OODA loop. Due to greater latencies in the adversary's loop then the friendly loop, the adversary's decisions are now based on observations of friendly operations.

Compelling an asymmetrical adversary to be reactive vice proactive is critical to mission success. An asymmetrical adversary's center of gravity is the ability to gather and control information. This makes it difficult for coalition forces to operate in various geographic regions of conflict. Interfering with an insurgent's ability to operate effectively is directly related to the capability of the U.S. military to insert itself in the adversary's OODA loop. An insurgency will not have the resources or motivation to continuously react to U.S. military operations.

Properly implemented, ECD is a tool that will enable tactical commanders to conduct proactive operations in order to inhibit the insurgency's OODA loop. ECD by itself is inadequate to provide useful intelligence. It must be combined with various other assets. Emplacement at a tactical intelligence cell will aid in focusing intelligence collection assets on newly acquired areas of interest (AOI), or reinforce current situational awareness of previously identified AOI's.

Greene's expanded OODA loop is depicted below.

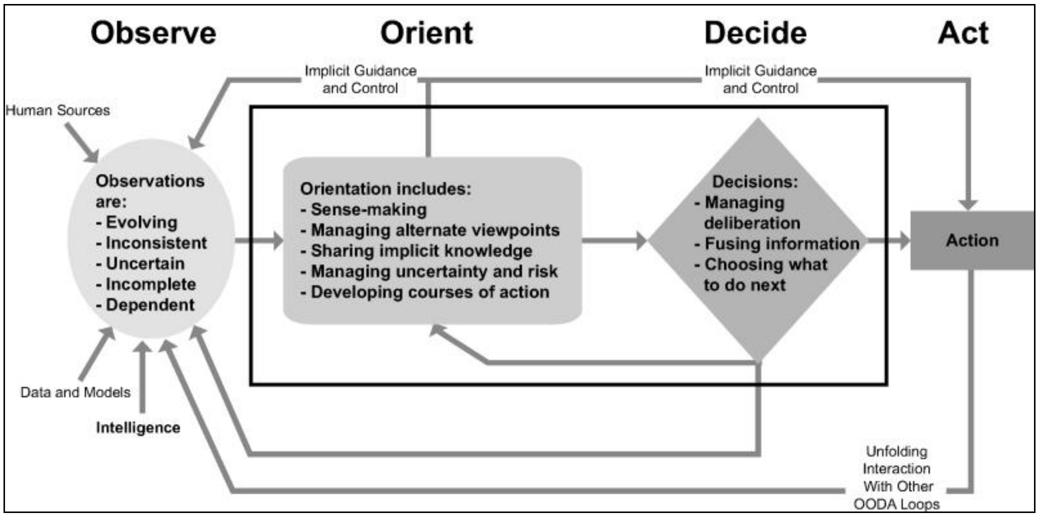

Figure 14. The Expanded OODA Loop (From Greene, 2007).

With respect to observations, ECD will allow the tactical analyst to observe information, and most notably trend analysis, in a different approach. This approach has the potential to orient the commander's attention to specific geographic locations and track insurgent trends. Following this orientation would be the decision to deploy forces based on a fusion of intelligence from various sources.

5. Tactical Need

Signals intelligence (SIGINT) is an intelligence discipline where the collection of raw data is rarely scarce, and more accurately, overly abundant. Having the manpower present to deal with this dilemma is a constant struggle within the SIGINT community. Mr. John Abe best describes this in a situation:

> How many signals are active in a 200 mile radius surrounding Frankfurt, Germany? Hundreds? Thousands? Now, add one more signal which happens to be one used by a terrorist communicating with other members of his cell. What are the chances of detecting the new signal within the first few seconds? The likelihood of detection is very low. In fact, detecting and identifying the signal as new is very unlikely even if the signal were up for five minutes or more. (Abe, 2005)

A technology exists that will have a significant impact on not only SIGINT specialists but also other operational units. As a decision support tool for the commander, it

- Aids SIGINT analysts in determining which signals are important and therefore need to be further analyzed
- Assists the decision-maker with respect to force selection and utilization.

The positive impact on the decision-maker will allow for more informed decisions on employment and deployment of forces, which type (kinetic versus non-kinetic effects) of forces to employ, and how to maximize the utilization of organic intelligence collection assets. However, like all technology, it must be properly implemented at the appropriate level of command and on the appropriate information dissemination system.

6. Signals Data Collection and Storage

This section is located in a classified appendix.

7. Leavitt's Approach to Organizational Change

Harold J. Leavitt, the Walter Kenneth Kilpatrick Professor of Organizational Behavior emeritus at the Stanford Graduate School of Business and a "pioneer in the development of the academic field of organizational behavior" (Horngren, 2007). His model articulates the interrelationships between tasks, structures, personnel, and technology within an organization. Figure 15 is a general illustration of the Leavitt Diamond.

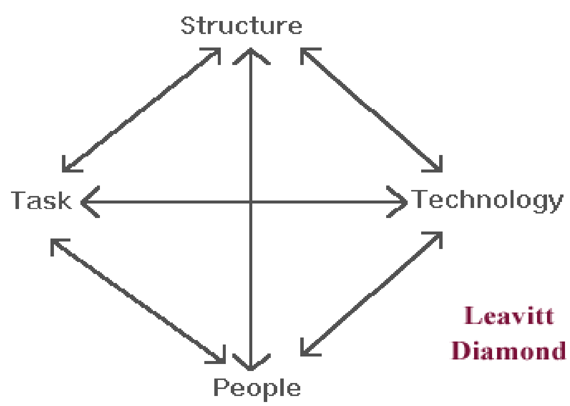

Figure 15. The Leavitt Diamond (From Horngren, 2009).

This change in technology will affect the personnel and structural organization, along with certain tasks that must be accomplished. Organization and workflow optimization are paramount in creating a streamlined operating procedure.

The focus of this experiment is relocating ECD to a tactical intelligence center in order to maximize the efficiency of organic collection assets and assist the commander in maximizing the effectiveness of forces. Consistent with Leavitt's model, once this relocation occurs (a change in technology), the remaining attributes of the diamond must be reviewed, and most likely altered, to ensure the organization is optimized with respect to efficiency of assets and effectiveness of forces. This reorganization will allow for the production of tactical intelligence in a timely manner.

B. CURRENT ENERGY PROCESS ARCHITECTURE

For all intents and purposes, the current process architecture can be simplified and analyzed as a two-phased process. Because of the need to maintain a queue for the RFIs, queuing theory is also used for analysis purposes. Appendix A diagrams the complexity of the process, beginning with the RFI submittal by a user in an operational theater. The process concludes once the RFI is fulfilled and returned to the originator.

1. RFI Submittal and Reception

The first phase commences when an RFI is submitted from theater and ends when the RFI is received by Analyst 1 (referred to as A1). Because ECD is in its infancy, it does not have a mature operating procedure, and therefore resides in an organization lacking 24/7 operations. This fact is detrimental to the timeliness of the entire process and is one reason why it cannot routinely produce tactical intelligence.

Since this organization is not conducting 24/7 operations, a probabilistic analysis of when the RFI is actually received by A1 is necessary. A1 works from 0700 to 1700, Monday through Friday, every week. Since a weekly routine is the first periodic unit of measure in A1's work cycle, all probabilistic outcomes will be in reference to a weekly schedule. The week is divided into 168 hours and in any one of these hourly timeslots an

RFI may be sent from theater to arrive in A1's inbox within minutes. All hourly timeslots, their associated latency for RFI reception, frequency of occurrence in a given week, and probability are presented in Appendix B.

The first step is finding the probability of A1 receiving an RFI during normal working hours. Since A1 works ten hours per day, there are fifty hours per week in which A1 receives an RFI within one hour. These are considered the best case scenarios because the latency due to an RFI sitting in a queue is minimal. "Within the hour" assumes that A1 has other distractions (coffee breaks, bathroom breaks, lunch, etc.) and daily tasks of a higher priority. Making these assumptions, an RFI received within one hour of A1 arriving to work will also be included with normal working hours. This means there are fifty-five hourly slots per week in which an RFI will be received during normal working hours.

The next-best case scenario is when and RFI is submitted during non-working hours from Sunday evening through Thursday evening. His scenario is when an RFI is received after the close of the business day with the next day being a normal business day. If an RFI is received during this time period, a latency of anywhere from one to fourteen hours is possible. There are thirteen hours a day for five days during a normal working week where this is the case. This scenario accounts for sixty-five hourly slots per week.

The remaining forty-eight slots occur over the weekend; from 1700 Friday evening through Sunday afternoon. This is the worst-case scenario where the latency range is from fourteen to sixty-two hours before A1 receives the RFI. Table 4 is the probability distribution per hour during one week when an RFI could be received.

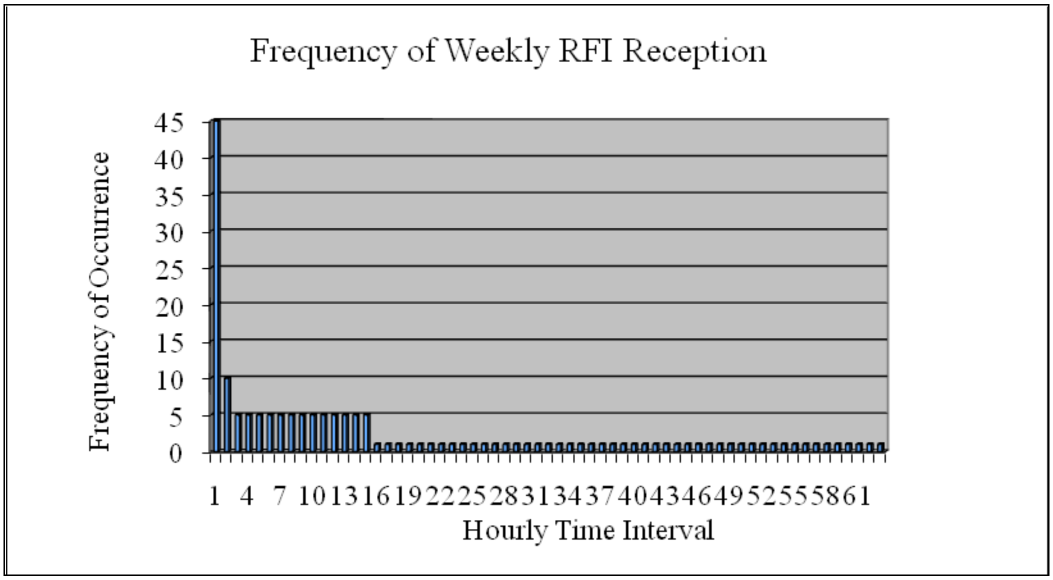

Table 4. Probability Distribution for Weekly RFI Reception.

The table shows a large discrepancies of possible values; an RFI can be received anywhere from within the first hour it was sent to sixty-two hours afterwards. Three focus areas are observed relating to the three scenarios described above. What is not overtly obvious from the previous table is that these areas are relatively equal time distributions. Figure 16 is a visual representation of the time distribution into these distinct categories.

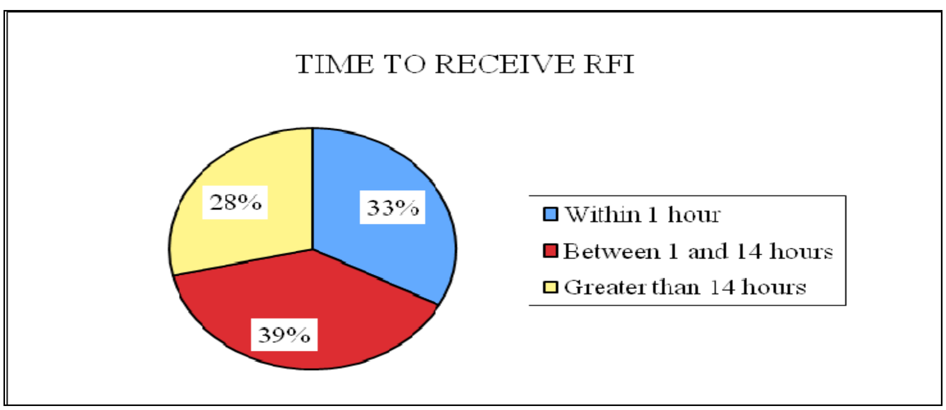

Figure 16. Scenarios of RFI Reception.

From this pie chart, one can clearly see that the probability of RFI reception within one hour, between two and fourteen hours, and greater than fourteen hours are relatively equal. That is to say, if an RFI was submitted at a random time, that RFI has approximately 33% probability of falling into any of the three scenarios. As previously stated, this latency in time is not a characteristic of tactical intelligence; and therefore needs to be eliminated.

From a probability distribution, an expected value can be determined. This expected value is more commonly referred to as the average, or mean. The mean value is also denoted as μ. The expected value, E(X), is computed by (Balakrishnan, 2007).[3]

$$E(X) = \sum_{i=1}^{n} X_i P(X_i) \tag{2.1}$$

In this equation, X is the time interval required before an RFI is received and P(X) is the probability of RFI reception during the time interval X. X and P(X) for this phase are located in Appendix A. The expected value of X is 14.4 hours.

Associated with the expected value of a probability distribution is the variance and standard deviation. Variance is defined as

$$Variance = \sigma^2 = \sum_{i=1}^{n} [X_i - E(X)]^2 P(X_i) \tag{2.2}$$

and the standard deviation is the square root of the variance, denoted as σ. For phase one of the current process, the variance is 300.8 and the standard deviation is 17 hours and 21 minutes. A large σ is indicative of a well spread probability spectrum and degrades the importance of the mean value. In this case, σ is larger than μ. Falling within one σ of the mean value accounts for approximately 68.26% of all values of X. For this phase, falling within one σ of the mean value is anywhere between zero (cannot account for negative time) and 31 hours and 45 minutes to receive an RFI. The following table is an area visualization of the probability distribution with the mean (red dashed line) and one standard deviation (yellow dashed line) clearly outlined.

[3] All equations throughout Chapter II and III, unless otherwise stated, are from this source.

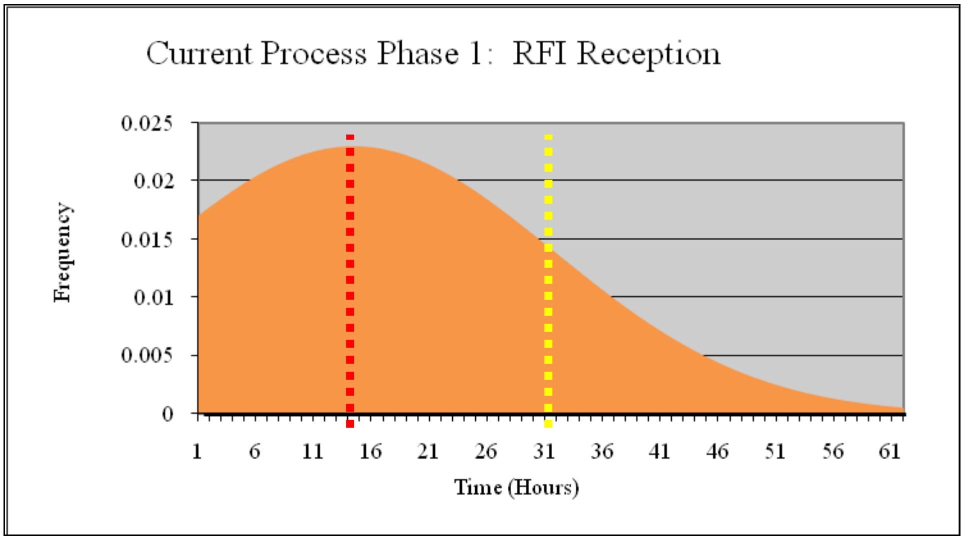

Figure 17. Phase 1 Probability of RFI Reception.

2. Analysis and RFI Fulfillment

The second phase of the current process begins once the RFI is received by A1 and concludes once the RFI is fulfilled and sent back to the RFI originator. This process is quite complex and involves interactions between A1 and Analyst 2 (referred to as A2) and is diagramed in Appendix A. This phase is also known as the production and dissemination phase.

Once an RFI is received, A1 sends the RFI to A2 so that A2 can setup the equipment to conform to what type of information is requested. Once the equipment setup is complete, A2 creates the desired report. This report is sent to A1 who reviews the report, checks it for accuracy, and formats the report per the RFI. Once formatted, A1 sends the requested information to the RFI originator.

In discussing the process during initial review, A1 declared that an RFI can be fulfilled (once received) anywhere from twenty minutes to six hours. Instead of analyzing each individual interaction between A1 and A2, it is sufficient for the purpose of this analysis to view the second phase as one process. This is because the time scale is much smaller than the time scale of the first phase (minutes vice hours). Since the latency of the overall process is of greatest importance, the individual interactions do not need to all be considered. However, priority of request will be considered when discussing queuing theory.

Since an RFI can be fulfilled anywhere within twenty minutes and six hours (based on priority of request and other daily tasks), it is safe to assume a general distribution of this phase. With the given range and knowledge of the work ethic A1 and A2 possess, μ is assumed to be 120 minutes, or two hours. Collaborating with A1, a σ of forty-five minutes is accurate, meaning 68.26% of all RFIs are fulfilled between 75 minutes (one hour and fifteen minutes) and 165 minutes (two hours and forty-five minutes). Figure 18 shows the normal distribution of this phase with the mean (red dashed line) and one standard deviation (yellow dashed line) clearly outlined.

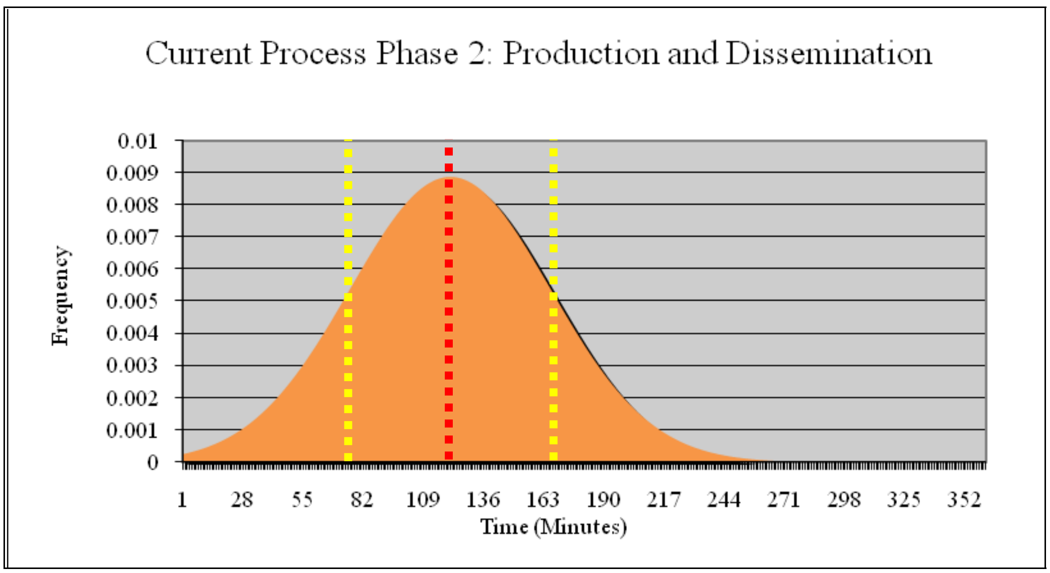

Figure 18. Phase 2 Normal Distribution.

3. Total Latency in the Current Process Architecture

The combination of both phases corresponds to the total latency of the current architecture. A simple summation of the mean values and variances from both phases is sufficient to describe the entire process.

$$\mu_{total} = \mu_1 + \mu_2 = 14.4 hours + 2 hours = 16.4 hours \tag{2.3}$$

$$Variance_{total} = \sigma_1{}^2 + \sigma_2{}^2 = 300.8 + (2e^{-5}) = 300.8 \qquad (2.4)$$

From the variance, the overall σ can be calculated by

$$\sigma = \sqrt{Variance_{total}} = 17.3 hours \qquad (2.5)$$

The following figure is the probability distribution curve of the entire process with the mean (red dashed line) and one standard deviation (yellow dashed line) clearly outlined.

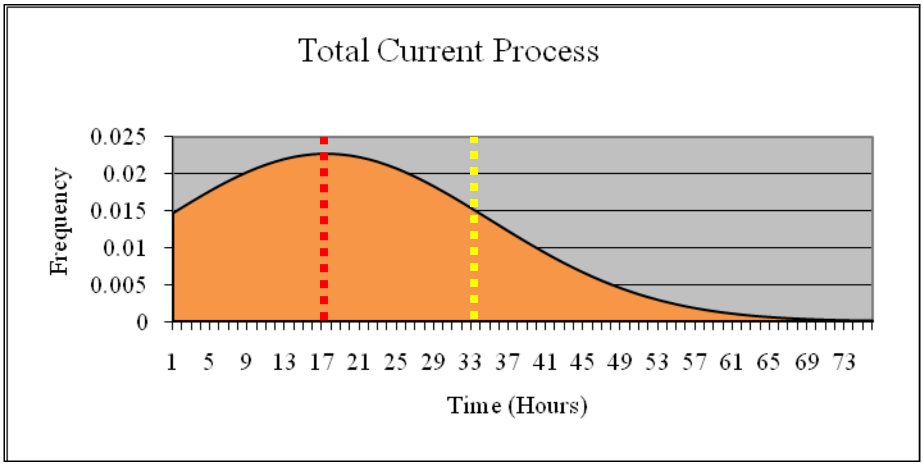

Figure 19. Overall Probability Distribution.

It is evident from these calculations that the system is not tailored for tactical intelligence dissemination. In a best-case scenario; however, an RFI may be fulfilled and disseminated within an hour, and therefore would aid a tactical military commander. These instances would rarely occur, and most likely only be used for an RFI of the highest priority. An example of this would be a time-sensitive target of a high-value individual. This RFI would come from the highest level of authority, and would be the focus of effort for both A1 and A2.

Currently, high priority tactical operations may occur simultaneously in multiple theaters. Because there are only two dedicated analysts, they may only be able to assist one of the operations. Thus far, the mean values and standard deviations have all been calculated based on *one* RFI. What if more than one RFI is received within a given timeframe? This is the case with the current process, and queuing theory needs to be analyzed.

4. Queuing Theory

In order to apply the correct queuing model, various assumptions must be made. These assumptions are (Balakrishnan, 2007):

- Arrivals that follow the Poisson probability distribution.
- First in, first out (FIFO) queue discipline.
- A single-phase service facility.
- *Infinite, or unlimited queue length.* That is, the fourth symbol in Kendall's notation is ∞.
- Service systems that operate under steady, ongoing conditions. This means that both arrival rates and service rates remain stable during the analysis.

Poisson probability distribution has assumptions discussed in the following section. FIFO, for the purpose of this analysis, is assumed. This assumption has been confirmed by A1. There are instances where FIFO is not followed; an example is when a high priority operation is being planned. When this occurs, all analysts are dedicated to this operation, disregarding FIFO. However, these occurrences are rare enough that over a long enough period of time, FIFO is the mean behavior.

Because all the processes involved are linear and dependent on completion of the previous process, it can be assumed a single-phase facility. Similar to the rationale for FIFO, occurrences where this process is viewed as multi-phased are limited and scarce. There is no limit to the RFI queue.

Steady state conditions are assumed over the entire analysis. The state of military operations throughout the world will dictate the definition of steady state condition. Current operations have been ongoing well before the beginning of this analysis and can be considered steady state. Before these assumptions are verified, the Poisson probability distribution and Kendall's notation are discussed.

a. Arrival Characteristic—Poisson Probability Distribution

Confirmation of four assumptions is necessary to utilize the Poisson probability distribution. These assumptions are (Balakrishnan, 2007):

- The average arrival rate (λ) over a given interval is known.
- This average rate is the same for all equal-sized intervals.
- The actual number of arrivals in one interval has no bearing on the actual number of arrivals in another interval.
- There cannot be more than one arrival in an interval as the size of the interval approaches zero.

All these assumptions are valid for the current process and the discrete Poisson distribution is provided by the following formula

$$P(X) = \frac{e^{-\lambda} * \lambda^{X}}{X!} \tag{2.6}$$

where X is the number of arrivals per unit time, P(X) is the probability of *exactly* X arrivals, λ is the average arrival rate, and *e* is the exponential constant. In order for this formula to be accurate for the current process, λ must be defined.

From 2008 historical data, 1,045 RFIs were submitted and fulfilled. Dividing the number of RFIs per year by the number of days per year produces about 2.86 RFIs received per day; or twenty received per week. Since the unit of time used is a week, λ equals twenty. Figure 20 is the Poisson distribution for the current process.

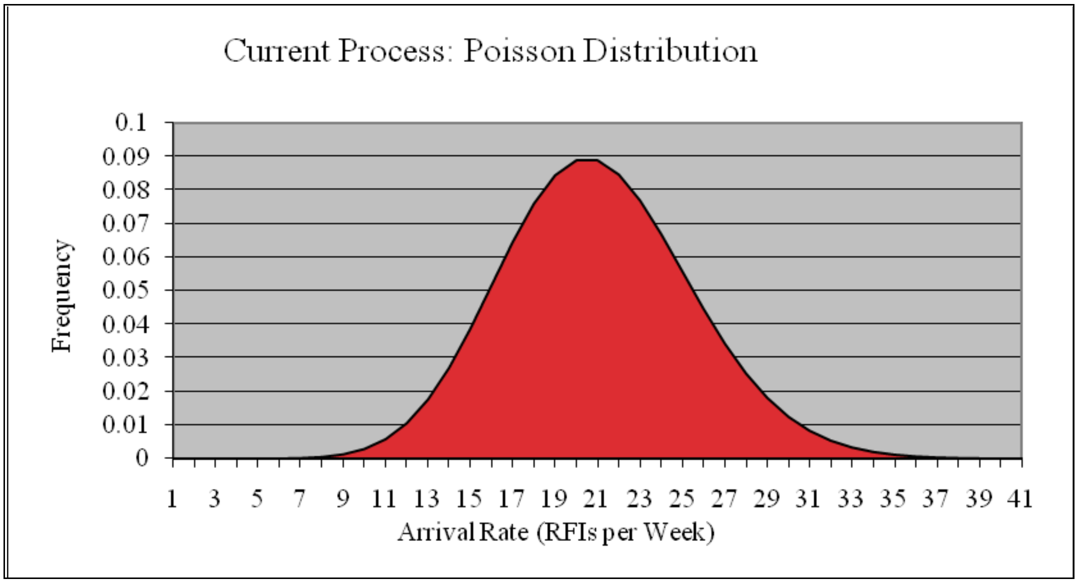

Figure 20. Poisson Distribution for the Current Process.

b. Queuing System Characteristics—Kendall's Notation

In queuing theory, there is a commonly used three- or five-symbol notation to organize the various types of systems. The notation is defined as (Balakrishnan, 2007)[4]:

A/B/s.

Where

- A = the arrival probability distribution. Typical choices are M (Markovian) for a Poisson distribution, D for a constant or deterministic distribution, or G for a general distribution with known mean and variance.

- B = the service time probability distribution. Typical choices are M for an exponential distribution, D for a constant or deterministic distribution, or G for a general distribution with known mean and variance.

- s = the number of servers.

[4] Balakrishnan uses the three-symbol vice the five-symbol notation. Only three-symbol notation will be used throughout this thesis.

The last two symbols identify the maximum allowable length of the queue and the size of the arrival population. The omission of these two symbols implies both criteria tend towards infinity (Balakrishnan, 2007).

The current process is best represented by an M/G/1 system. As stated above, the arrival of RFIs is a Poisson probability distribution, the service time is represented by a general distribution with a known (assumed) mean and variance, and the number of servers is singular. The product A1 and A2 collectively assemble is a linear process and thus represented as a single server. Multi-servers indicate that an RFI would go to either A1 or A2 for fulfillment, and this is not the case.

c. Queuing Computations for the Current Process Architecture

For computations involving an M/G/1 system, the average number of arrivals per time period (λ), the average number of people or items served (ψ), and the standard deviation (σ) are essential. From previous calculations, λ = 20 arrivals per week, ψ = 21 products per week, and σ = 0.75 hours (0.00446 weeks). It is important to note that the service rate must be greater than the arrival rate, otherwise the queue would tend towards infinity. With these values of λ, ψ, and σ, the following six computations encompass the operating characteristics of this M/G/1 model (Balakrishnan, 2007):

Average server utilization time:

$$\rho = \frac{\lambda}{\psi} = 0.952 = 95.2\% \tag{2.7}$$

Average number of customers or units waiting in line for service:

$$L_q = \frac{\lambda^2\sigma^2 + \rho^2}{2(1-\rho)} = 9.1 \tag{2.8}$$

Average number of customers or units in the system:

$$L = L_q + \rho = 10.05 \tag{2.9}$$

Average time a customer or unit spends waiting in line for service:

$$W_q = \frac{L_q}{\lambda} = 0.455 weeks = 3.2 days \tag{2.10}$$

Average time a customer or unit spends in the system:

$$W = W_q + (1/\psi) = 0.5 weeks = 3.5 days \qquad (2.11)$$

Probability that there are zero customers or units in the system:

$$\rho_0 = 1 - \rho = 0.048 = 4.8\% \qquad (2.12)$$

From these calculations, the current process maintains about nine RFIs in the queue at any given time, and total of ten RFIs (nine in the queue and one in production) are constantly in the system. The average server utilization time describes the amount of time that A1 and A2 are working an RFI. Because there are other daily tasks associated with their jobs, the other tasks have already been taken into account when calculating the second phase of the current process. P_0 conveys that the model has a low probability (less than five percent) of ever being void of RFIs that require attention.

The values of W_q and W reveal the true message of the current ECD process analysis. Unless there is a high priority operation, an RFI will spend in excess of three and a half days in the system. This calculated value is optimistic because A1 stated that the average time to fulfill an RFI was approximately five days. This latency in fulfillment is not suitable for an RFI to be submitted with the intent of providing tactical intelligence, since actionable tactical intelligence is associated with *timeliness.* The proposed architecture will provide users with all the same intelligence they can currently acquire through submission of an RFI, but will also include a capability to acquire *timely* intelligence to provide useful insight to tactical commanders prior to conducting operations; no matter how high the priority of the operation.

C. SUMMARY AND CONCLUSIONS

The current process architecture cannot provide timely intelligence to a tactical user nor can it fulfill a high volume of RFIs based on the personnel and organizational structure. This initial structure served as the experimental test bed for this technology. Now, the technology has proven useful and requires a mature operating procedure to efficiently service users at every level of warfare. The following characteristics of the current process are areas of possible improvement with respect to the production of tactical intelligence.

The current process was established as a test bed for verification and validation of ECD technology. While ECD has proven useful to fulfilling RFIs on the time scale involving days, a timeline on the order of hours and minutes is not feasible in the current architecture. Appendix C is a PowerPoint presentation, created by the author, given to a senior executive with the intent of demonstrating the feasibility and tactical utility of ECD. The presentation was given on February 26th, 2009. The following five sections list and explain the areas of latency in the current process. Providing senior leadership metrics and avenues of improvement will allow for funding and expedited implementation of this technology at the tactical level in support of the GWOT.

1. Information versus Intelligence

Differentiating between information and intelligence has been done in a previous section. Currently, an RFI must be fulfilled with a fully vetted intelligence report, with few exceptions. This is not driven by policy, but is a function of what information a specific RFI is requesting. An intelligence report is more time consuming than merely providing information to the requestor, because intelligence requires a certain level of analysis. In many cases, if just the information was provided to the RFI originator, that unit can conduct its own analysis and produce its own intelligence. There are situations where a military unit has the organic intelligence assets necessary to gather their own intelligence with a "tip off" from the information provided by the strategic operations center. These changes would allow for a higher volume of RFIs to be fulfilled and decrease the amount of time it takes to fulfill a request.

2. "Pushing" versus "Pulling" Information

In order for the current process to initiate, the system requires submittal of an RFI via a member of the tactical unit in a theater of operations whom desires the information (the RFI originator). Before an RFI is submitted, the RFI originator needs access to the Joint Worldwide Intelligence Communications System (JWICS) and an understanding of:

- The observed intelligence gap that could be detrimental to mission success.

- What information is required to fulfill this gap.
- The capabilities and limitations of this technology.
- The EM spectrum and what information it can provide.

Once all these stipulations are met, than the tactical unit “pushes” an RFI to the operations center where this technology currently resides. Once A1 and A2 complete the necessary analysis to fulfill the RFI, the final intelligence product is than “pushed” back to the RFI originator. This is equivalent to having to “pull” the required information from the operations center. If there is any rework required, or the findings of the RFI give birth to new questions, than another RFI must be submitted.

A solution to decrease the latency in the process would be to constantly “push” the information to units at all levels periodically, partitioning the information based on geo-location of the military unit. If military units were periodically receiving pertinent information based on their area of operations, their indigenous intelligence cell could, in most cases, provide the required analysis on the information to provide *timely* and actionable intelligence to the commander. This information would also provide the intelligence cell information necessary to more efficiently focus their organic intelligence collection assets.

3. Bottleneck

Anyone worldwide, with access to JWICS (or access to a HHQ with JWICS), can submit an RFI. Since there are only two analysts currently assigned to this technology, an informational bottleneck occurs. Tactical operations in various theaters across the globe prioritize intelligence requests based on the current mission in their respective theater. Different theaters have a higher priority than others. Since all the RFIs are sent to a single strategic-level operations center and placed in a queue, the relative importance of the information requested does not matter. An obvious exception to the rule would be a tactical operation with strategic implications, and this category of operation is usually time-sensitive. Even though an RFI in one theater might be of higher priority than another RFI in a separate theater does not mean the queue will acknowledge this, unless (as previously stated) there are strategic level implications. There needs to be a way to geographically separate the information in order to prioritize requests.

4. Human-in-the-Loop

Human analysis at the strategic level is not necessary if ECD is located at the tactical level. Once ECD "pushes" the information to the tactical user, organic intelligence analysts can use the information appropriately. Eliminating the need to produce fully vetted intelligence reports creates an architecture where the human involvement tends to zero; except for when the information needs to be analyzed. Implying that the human can be fully removed from the model is incorrect, as there will always need to be someone conducting routine and ad hoc maintenance on the hardware. However, for the purpose of this thesis, complete removal of the human-in-the-loop with respect to daily tasks is possible, and recommended. Again, this can only be recommended if the final ECD product is *not* a vetted intelligence report, but an information "push."

5. Clearance and Access

Currently, ECD only resides on JWICS. This limits the number of potential users to only those who have the appropriate clearance level and access to high-side systems. This is not always the case in an operational environment. A common axiom realized by military veterans of Operation: IRAQI FREEDOM and Operation: ENDURING FREEDOM (OIF and OEF) is that "the war is fought on the SIPRNet."

During OIF, the author was deployed to a forward operating base (FOB), which did not have direct access to JWICS. If ECD was available on JWICS during this deployment, the author would have needed to send an RFI to his higher headquarters (HHQ), who in turn would have had to send the ECD RFI back to CONUS. Once the RFI was fulfilled, it would have been sent back to HHQ who would then have to reformat the product to transfer from JWICS to Secret Internet Protocol Router Network (SIPRNet). Once reformatted, then it could have been sent back to the author, with obvious time delays. There are obvious time delays with the extra steps detailed above.

The scenario described above would not have been feasible to produce tactical intelligence for the author. However, if ECD resides on JWICS and the SIPRNet, the potential number of users would increase. If the war is fought on the SIPRNet, then ECD should be applied appropriately.

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III. PROPOSED ENERGY PROCESS ARCHITECTURE

A. OVERVIEW

The proposed process will mitigate many of the sources of latency detailed in the previous section in order to allow for the production of tactical intelligence. ECD will also be a tool which the tactical commander can use to pull timely and actionable information. Cloud computing is the backbone of the proposed solution with various regional hubs with service to distinct areas of operations.

1. Database and Storage

The data stored and archived in the database will be geographically partitioned into various regions of the world. This is a shift from the classic hub and spoke model, seen in Figure 21, to a more distributed hybrid of a hub and spoke model.

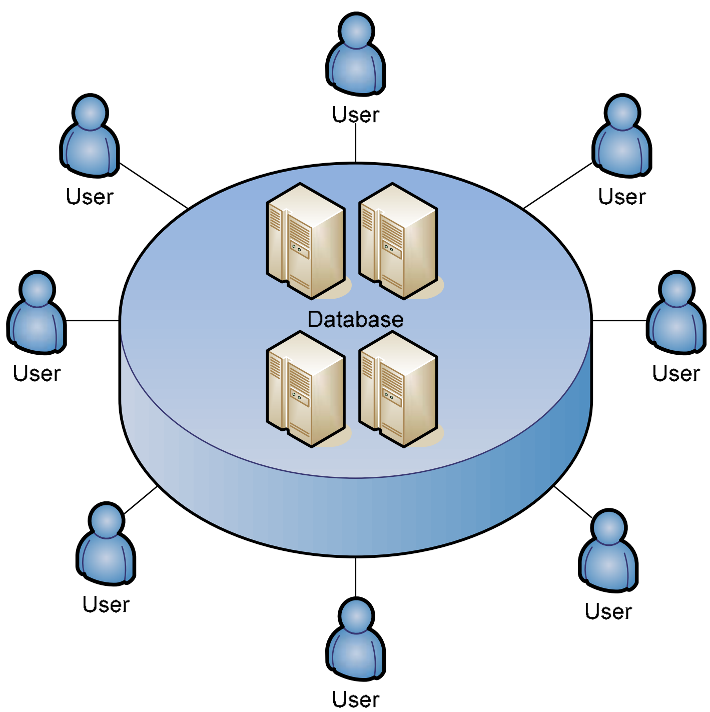

Figure 21. Hub and Spoke Database Architecture.

In the hybrid model, the databases are geographically disbursed and interconnected with all other database hubs. Users at each geographic location will have access to all pertinent data. The hybrid database architecture alleviates the bottleneck, described in Chapter II, of worldwide users requesting information from one database. Displayed in the next figure is the hybrid architecture concept.

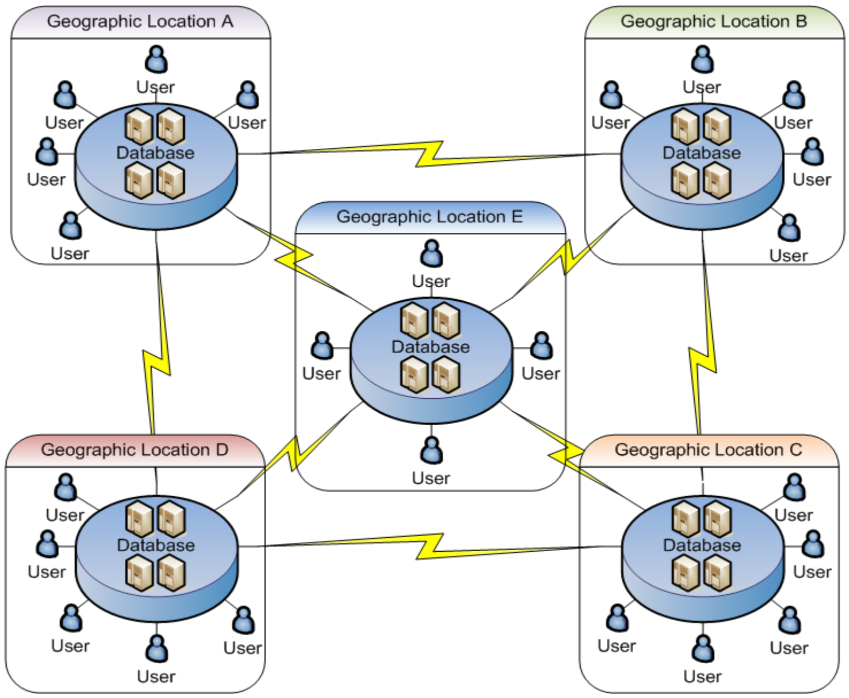

Figure 22. Hybrid Hub and Spoke Database Architecture.

Also evident from the above figure is the number of users who can have simultaneous access to the data. Multiple users in multiple theaters may now use the data for informational and intelligence purposes *without* submitting an RFI to CONUS. This data "push" to various locales worldwide versus the RFI submittal process was noted as one of the sources of hindering tactical intelligence production.

The current architecture resides on JWICS. The proposed architecture also resides on JWICS; however, it also has a mirrored architecture on the SIPRNet. Figure 23 shows two hybrid architectures, one for each information dissemination system. This model shows that every node with JWICS access will also have SIPRNet access. However, the converse is not true. There are many locations in support of OIF and OEF where there is SIPRNet acces, but no JWICS access. These two dissemination systems are not linked and have no cross-domain transfer capability.

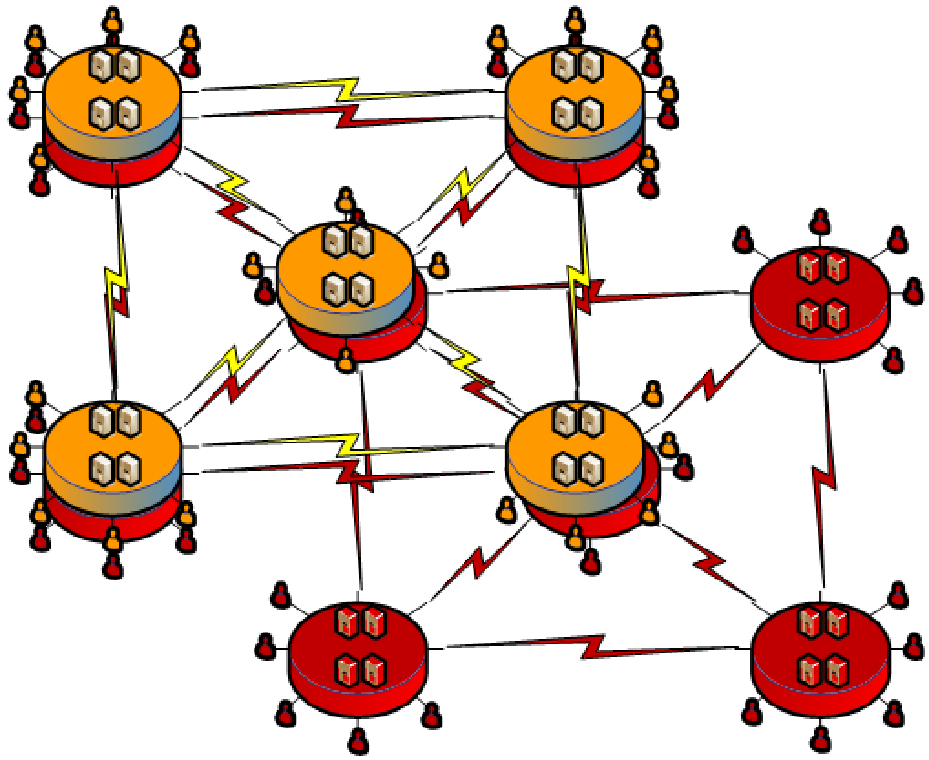

Figure 23. The Proposed SIPRNet (Red) and JWICS (Orange) Architectures.

Another observation of the current architecture was that ECD is limited to JWICS users. Existing on the SIPRNet will provide access to more users simply because more personnel have secret clearances. The overlap seen above demonstrates that not all regional hubs will have access to JWICS. Some areas or operations are too remote for JWICS access. No matter how remote, military personnel should have access to the information ECD provides.

A level of fidelity is lost in the data that resides on JWICS and also resides on the SIPRNet. However, the relevant data necessary for the tactical commander to use in determining the employment and deployment of forces is contained in the SIPRNet database. What is lost is the ability to conduct an in-depth analysis of the signals of interest. The equipment necessary for a more comprehensive analysis only resides with units that have direct access JWICS. The tactical commander would have the reach-back capability to HHQ with JWICS, if the need for this level of analysis exists.

2. Cloud Computing

Cloud computing has an abundance of definitions. This is a fairly new and evolving technology and is integrated into the database architecture in the above section. As Erdogmus states:

> According to Wikipedia, cloud computing refers to the use of scalable, real-time, Internet-based IT services and resources, incorporating beyond [software as a service] many key technology trends of the 2000s. These trends include . . . service-oriented architecture, application service provision, Web 2.0, Web services, mash-ups, utility computing, autonomic computing, grid computing, on-demand computing, and so on. . . . Matthieu Hug's alternative definition on InfoQ (www.infoq.com/articles/will-meis-replace-extranets) is . . . "an emerging computing paradigm where data and services reside in massively scalable data centers and can be ubiquitously accessed from any connected devices over the Internet. (Erdogmus, 2009)

These varying definitions provoked Erdogmus to ask a "cloud-computing pundit for the real story: Marin Litoiu of York University" and as maintained by Litoiu, "cloud computing is an emerging computational model in which applications, data, and IT resources are provided as services to users over the Web" (Erdogmus, 2009).

Important to note is that the proposed database architecture and integration of cloud computing is already occurring. It is not the intent of the author to be credited with the transformation to cloud computing, for that transformation is independent of ECD. ECD will be one of many applications. For all intents and purposes, this thesis focuses on an ECD application as the proposed solution that will exist in "the cloud."

3. ECD Application

As an application, the user will see two main sections on the computer monitor. These two sections are the query window and map. The map will display the geographic area of interest and can be zoomed in and out. The query window will allow the SIGINT analyst to focus on particular signals of interest (SOIs) within a given time interval. The actual query sets are not listed here due to classification. The following figure is a cartoon rendition of the ECD application graphical user interface.

Figure 24. ECD Application Graphical User Interface.

4. Required Training

With the introduction of any new technology, a training regimen must be crafted concurrently in order to increase the effectiveness of said technology to the specific organization. This is a major pillar in Leavitt's Diamond and described in Chapter II. The details of the training process will be assembled by the SIGINT professionals whom currently are testing ECD and are not in the realm of this thesis; the author does not have the technical expertise or background to create this training curriculum.

5. Latency and Queuing Theory

a. Total Latency for the Proposed Process Architecture

The proposed process can be viewed as a single phase system conducting around-the-clock operations. ECD will be operational 24 hours per day by a single individual. Current military operations mainly use either two 12-hour shifts or three 8-hour shifts by individuals to cover 24 hour manning. Slightly compressing the timeline from the current process proposed by A1 and A2 is possible due to:

- The analyst's familiarization of the EM environment in a given area of operations.
- Focus on a relatively small (versus worldwide) geographic area.

- The analyst's speed and efficiency due to constant exposure to the ECD tool.

For the proposed process, μ is assumed to be 105 minutes, or one hour and forty-five minutes and σ is also compressed to thirty minutes. This means 68.26% of all products are disseminated between 75 minutes (one hour and fifteen minutes) and 135 minutes (two hours and fifteen minutes). Figure 25 shows the normal distribution of this phase with the mean (red dashed line) and one standard deviation (yellow dashed line) clearly outlined.

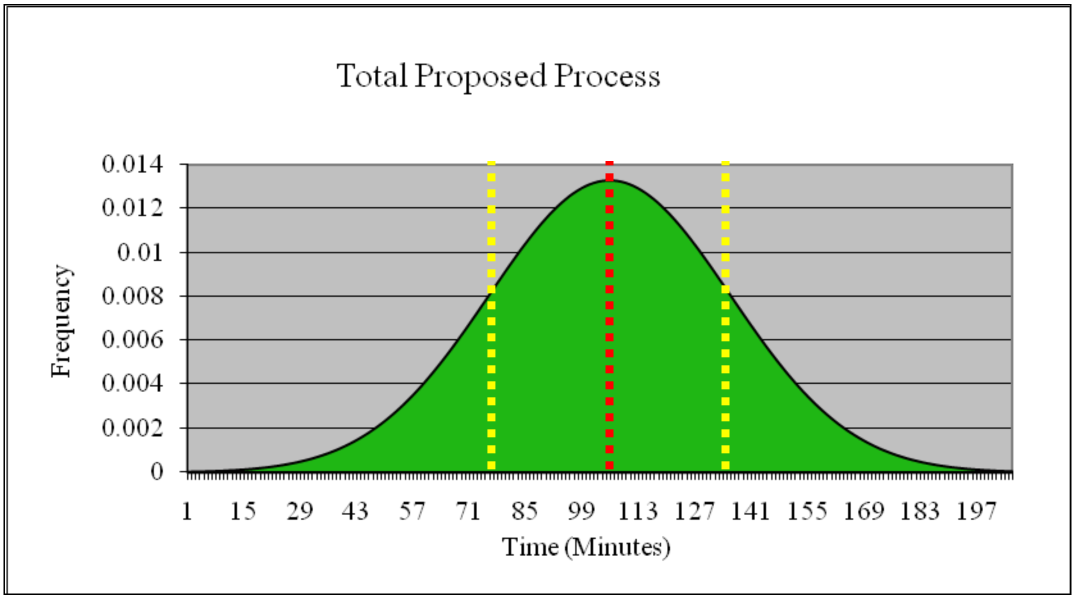

Figure 25. Proposed Process Normal Distribution.

b. Queuing Computations for the Proposed Process Architecture

The proposed process is best represented by an M/G/1 system, as is the current process. The average number of people or items served (ψ) is computed by taking the average time to produce an artifact based on a 24-hour operations center. At the average time of 105 minutes, just over thirteen requests per day could be fulfilled. Understanding that some requests would require more analysis, ψ = 12 products per day or 84 products per week. Since the average number of arrivals per time period (λ) must be less than ψ, a value of 11 products per day (77 products per week) is reasonable. This value for λ is also defendable due to the high operational tempo of a 24 hour tactical intelligence cell. The standard deviation was compressed from 45 to 30 minutes, meaning σ = 0.5 hours (0.00298 weeks). All calculations will be in the same units as those derived in Chapter II for comparison purposes. With these values of λ, ψ, and σ, the following six computations encompass the operating characteristics of this model:

Average server utilization time:

$$\rho = \frac{\lambda}{\psi} = 0.917 = 91.7\% \qquad (3.1)$$

Average number of customers or units waiting in line for service:

$$L_q = \frac{\lambda^2\sigma^2 + \rho^2}{2(1-\rho)} = 5.4 \qquad (3.2)$$

Average number of customers or units in the system:

$$L = L_q + \rho = 6.32 \qquad (3.3)$$

Average time a customer or unit spends waiting in line for service:

$$W_q = \frac{L_q}{\lambda} = 0.07 weeks = 0.49 days = 11.76 hours \qquad (3.4)$$

Average time a customer or unit spends in the system:

$$W = W_q + (1/\psi) = 0.082 weeks = 0.57 days = 13.76 hours \qquad (3.5)$$

Probability that there are zero customers or units in the system:

$$\rho_0 = 1 - \rho = 0.083 = 8.3\% \qquad (3.6)$$

From these calculations, it is evident that the queue has been reduced by an order of magnitude (hours vice weeks). However, it is *not* evident that tactical intelligence production is a common capability with a queue time of than double what the author has determined as acceptable for tactical intelligence production.[5] This length of time spent in the system (13.76 hours) is a result of assuming that the SIGINT analysts will be kept busy with ECD because it will be such a useful tool at the tactical level and the stipulation that FIFO is assumed. Any single request in the queue can be fulfilled if

[5] The author has defined tactically acceptable intelligence as requiring less than six hours to produce.

that requirement is time sensitive, disregarding the FIFO requirement. At the tactical level, infrequently would there be more than three time sensitive requests which must be fulfilled concurrently[6]. With an average fulfillment time of 105 minutes, up to three time sensitive requests could be fulfilled in order to be considered intelligence driving tactical operations. If there are more than three, another geographic location with the ECD application could be used to augment the tactical scenario in question.

B. SUMMARY

Instead of being situated in a single strategic operations center, ECD will be integrated with another program that is utilizing cloud computing as a way to geographically separate the required databases which ECD processes. ECD will then exist in the application layer of "the cloud." This will allow multiple users in multiple theaters to use ECD regularly without the need to send and RFI to CONUS. ECD relocation will lead to the capability to regularly produce tactical level intelligence in multiple theaters simultaneously. The database reorganization will occur at both the JWICS and SIPRNet levels, permitting access to more users at various clearance levels.

[6] "Tactical level" in this scenario is defined to be at the USMC Battalion level.

IV. COMPARISON AND ANALYSIS OF ARCHITECTURES

A. TIMELINESS OF INFORMATION

1. Latency Comparison

Examining both charts (Figure 26) of the current and proposed processes side-by-side provides a useful visual representation of the magnitude of latency eliminated from the process. It is important to note that the proposed architecture is an entire order of time magnitude (Minutes versus Hours) less than the current architecture. This decrease in latency allows for the production of tactical intelligence.

The combined graph in Figure 26 labeled "Current and Proposed Comparison" illustrates the disparity in visual representation when both scenarios are overlaid on the same axis in the same unit of measurement. The frequency of occurrence skews the graph because there is approximately one hundred percent chance an RFI will be fulfilled within four hours. Compressing the horizontal axis of the proposed process forces an expansion of the vertical axis of the same process. With this expanded range in frequency, the graph of the current process appears to have compressed horizontally. This graph shows the extreme decrease in time required to fulfill an RFI. The dotted green lines breakout the proposed process and changes the units of the horizontal axis to minutes. The solid orange lines breakout the current process and do *not* change the unit of measure of the horizontal axis.

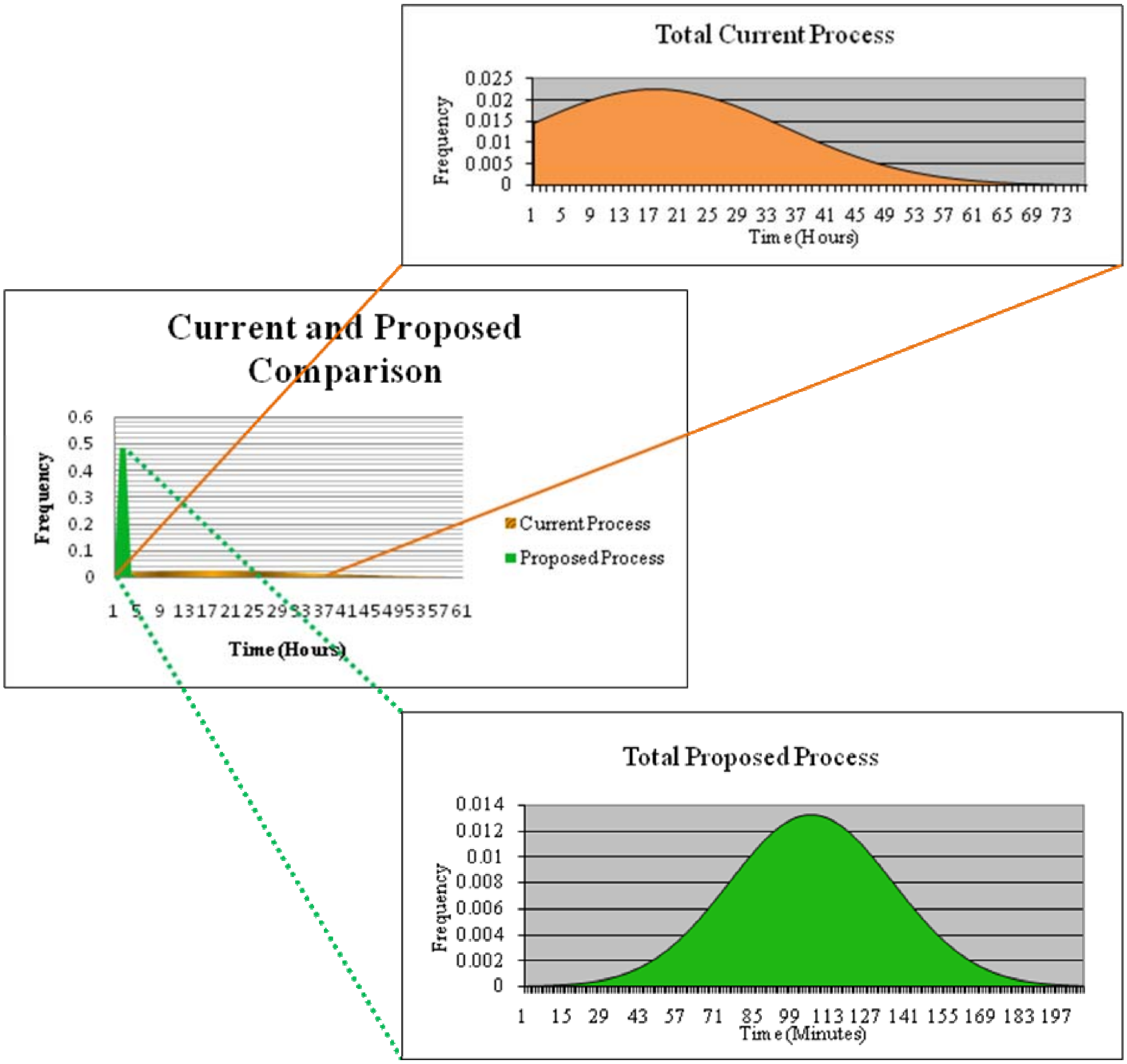

Figure 26. Current (Top) and Proposed (Bottom) Overall Latencies and a Comparison of Both Architectures (Middle).

When analyzing both architectures independent of queuing theory, they can each handle the production of one tactical intelligence product. However, the current process can only handle a couple of these routinely, and they would be based on the priority level of the requesting unit. The proposed solution allows for near continuous production of tactical intelligence products, if that is what the tactical commander requires. Prioritization of desired intelligence products would be focused in a smaller geographic region due to the new location of the ECD application, allowing more tactical operations to implement ECD.

2. Queuing Comparison

Not only is the overall timeline compressed, but there are other gains to the proposed process architecture. Another important aspect of relocating ECD to a tactical intelligence cell focused on a particular theater of operations is observed in the sheer volume of requests fulfilled per unit time. This is a function of:

- Having a single SIGINT analyst focused on the ECD application at any time during normal operations.
- Minimal other daily tasks assigned to the ECD analyst.
- Operating 24 hours per day, 7 days per week.
- Familiarization of the SIGINT analysts with the EM environment in that particular operational theater.

QUEUING THEORY METRICS	CURRENT	PROPOSED
Average number of arrivals per week.	20 (Global)	77 (Theater)
Average # of people or items served per week.	21 (Global)	84 (Theater)
Average server utilization time. (%)	95.2	91.7
Average # of customers waiting in line for service.	9.1	5.4
Average # of customers or in the system.	10.05	6.32
Average time a customer spends waiting for service.	3.2 Days	11.76 Hours
Average time a customer spends in the system.	3.5 Days	13.76 Hours
Probability that zero customers are in the system. (%)	4.8	8.3

Table 5. Comparison of Queuing Theory Metrics.

As declared at the end of Chapter III, the proposed timeliness is higher than the queuing theory metrics due to the FIFO requirement for an M/G/1 system.

3. Overall Timeliness Comparison

Providing ECD to a tactical intelligence cell with a revised operating procedure will increase the timeliness of the information flow to the SIGINT analyst. The subsequent table compares the two architectures with respect to various metrics.

COMPARISON	CURRENT	PROPOSED
Does the process require an RFI to CONUS in order to begin the process?	Yes	No
Once information is desired, when does the process begin?	When received in CONUS.	Instantly
What is the average time to fulfill an information request from the queue?	3.5 Days	13.76 Hours
How large is an area of interest per ECD location?	Global	Operational Theater
In one operational theater, how many requests can be worked at once?	One or Two	Many
When a high value operation is planned, how quickly can ECD produce actionable intelligence?	Hours	< 60 Minutes
Capable of providing general situational awareness to commanders?	Yes	Yes
Capable of routinely assisting tactical operations?	No	Yes

Table 6. Comparison of Tactically Important Metrics.

There are a few assumptions that allow this table to be accurate. First, it is assumed that the analyst at the tactical level has been trained and is familiar with the technology. The analysts currently using ECD at the strategic operations center are very experienced analysts with decades of operational knowledge in the field. Since ECD would reside in multiple theaters, the analyst in any particular theater will be familiar with the EM environment in that particular area of operations.

B. INFORMATION GAINED BASED ON UNCERTAINTY

1. Overview

Danskin, in his theory of reconnaissance, applies information theory to quantify "the optimum distribution of aerial reconnaissance effort against land targets in the presence of decoys" (Danskin, 1962). The information gained is a function of the amount of reconnaissance effort associated with a given region. Both before and after a reconnaissance, the information is quantified using the various probabilities of uncertainty coupled with that given region.

Danskin's theory was focusing on land targets with probabilities associated with them. These probabilities for a given region include:

$$p_0 = \text{There is no target.}$$
$$p_1 = \text{There is a decoy.}$$
$$p_2 = \text{There is a target.}$$

The summation of these probabilities is one. The different probabilities will be redefined based on signals per region. This section will look at Danskin's theory and apply it to a tactical intelligence center with ECD as an organic asset.

2. Computations

Transforming Danskin's theory to the realm of a SIGINT analyst is possible, if the right variables are chosen.[7] Before proceeding with this transformation to the ECD application, a few assumptions and understandings need to be stated. The SIGINT environment deals with many probabilities based on collection assets and techniques to include the probability of false negative (or false detection), the probability of intercept, and the probability of not locating the target. These probabilities are resident, and will continue to reside with ECD applied to the signals data and are not discussed or

[7] All equations in this section, unless otherwise noted, come from Danskin's "A Theory of Reconnaissance: I."

accounted for in this analysis. ECD does not alter the data collected. All issues associated with the collected data do not dissipate. ECD is merely another way to examination and filter a signals database. It is not the intent of this analysis to challenge any technical analysis of signals and/or the probability related to the technical analysis of signals. The following probabilities are simply related to the output of ECD overlaid on a geographic region.

The computations begin with the uncertainty of a region and probability associated with this uncertainty. There is a signal probability associated with each region, p_i, where:

$$\sum_{i}^{n}(p_i,...,p_n)=1$$

For ECD these can be redefined as:

p_0 = There is no signal.
p_1 = There is a signal of interest (SOI).
p_2 = There is a signal not of interest (SNOI).

In this scenario, $p_0 + p_1 + p_2 = 1$.

The uncertainty for a given region *before any reconnaissance* is defined as:

$$U(p_0,p_1,p_2)=-C\sum_{i=0}^{2}[p_i\log_2(p_i)] \quad (4.1)$$

After the reconnaissance is conducted, the probabilities will differ from those before the reconnaissance. A probability *after reconnaissance* is notated as p'_i. The uncertainty for a given region *after reconnaissance* is defined as:

$$U(p'_0,p'_1,p'_2)=-C\sum_{i=0}^{2}[p'_i\log_2(p'_i)] \quad (4.2)$$

For this thesis p_i represents the probabilities of uncertainty prior to the utilization of ECD. The probability *after* the utilization of ECD is denoted as p'_i. The worst case scenario is when all the probabilities are relatively equal; meaning $p_0 = p_1 = p_2 = (1/3)$. When these three probabilities are equal, uncertainty is maximized because no leverage can be given to either decision. In this case, $U(p_0, p_1, p_2) =$ 0.477*C. On the opposite end of the spectrum, a case where $p_0 = 0.001$, $p_1 = 0.001$, and $p_2 = 0.998$ produces a low uncertainty of 0.0069*C. Here, there is a very high certainty that p_2 is the solution.

The information gained concerning a particular region is the function I(x) where x equals the amount of effort devoted to that region. Danskin defines the information gained from a reconnaissance as the uncertainty after the reconnaissance subtracted from the uncertainty before the reconnaissance, or:

$$I(x) = U(p_0, p_1, p_2) - U(p'_0, p'_1, p'_2)$$

I(x) can be rewritten as:

$$I(x) = -C\sum_{i=0}^{2}[p_i \log_2(p_i)] + C\sum_{i=0}^{2}[p'_i \log_2(p'_i)] \tag{4.3}$$

This value of I(x) is referred to as “the entropy of a finite scheme” (Khinchin 1957) equating the amount of uncertainty to information entropy.

The uncertainty example above, where $U(p_0, p_1, p_2) =$ 0.477*C, can demonstrate how the information will increase. Take the scenario with a very low uncertainty as the probabilities associated with a region *after the reconnaissance* (or Post-ECD). This would mean $p'_0 = 0.001$, $p'_1 = 0.001$, and $p'_2 = 0.998$ yielding $U(p'_0, p'_1, p'_2) =$ 0.0069*C. In this case $I(x) = U(p_0, p_1, p_2) - U(p'_0, p'_1, p'_2) =$ 0.477*C – 0.0069*C = 0.47*C. The scenario takes a region of high uncertainty, filters it, and produces a region of very low uncertainty that yields a high uncertainty differential with an informational output value multiplied by some constant.

With respect to ECD, p_i represents the probabilities of uncertainty prior to the utilization of ECD. The probability *after* the utilization of ECD is denoted as p'_i. This equates to the amount of information gained depends the amount of uncertainty in the region eliminated by ECD. SIGINT analysts want to decrease uncertainty; however, they want to decrease it in a certain way. Concerning the probability of signals, the analysts want to maximize the combination of p_0 and p_1 and minimize p_2. The situation above, where p_2 was maximized, is useless to a SIGINT analyst because that means that most of the signals on the map are SNOIs. If most signals are not of interest, the analyst must still allocate man hours searching for SOIs.

3. Selected Scenarios

The following two scenarios will quantify the information gained using ECD. The first scenario is dedicated to a region that is densely populated. A sparsely populated region is the focus of the second scenario. Appendix D shows the Microsoft Excel spreadsheet with the calculations and formulas for both of the following scenarios.

a. Densely Populated Region

Consider a highly populated geographical area, most likely a major city. Now consider the amount of signals jammed into this relatively small geographical location. A snapshot in time of the EM environment in a major populated area is obviously difficult for a SIGINT analyst to tackle due to the vast number and types of signals in a small region. Finding an SOI is extremely difficult.

In this setting, p_0 would equal zero. Since the logarithm function of zero is undefined, this terms falls out of the summation. Now it is paramount to consider the probabilities of SOIs versus SNOIs. It is assumed that a major city will have a very small number of SOIs as compared to SNOIs simply because most of the population is not communicating a signal considered interesting to a SIGINT analyst. This assumption allows p_1 to be extremely low compared to p_2. The probability of an SOI is set at less than one percent, or $p_1 = 0.005$ generating $p_2 = 0.995$ since the $p_0 + p_1 + p_2 = 1$.

After running ECD on this geographic area, the result is a less cluttered snapshot of the EM environment. Since ECD eliminates the redundant signals, the value of p'_0 will increase. This increase will yield an increase in p'_1 also because the redundant signals tend to be SNOIs vice SOIs. Taking the following values of p'_i:

$$p'_0 = 0.40$$
$$p'_1 = 0.01$$
$$p'_2 = 0.59$$

Inserting these values[8] into equation (4.3) produces I(x) = (-1.0)*C.

These results are counterintuitive due to the negative value associated with the calculations. Given that, the overall uncertainty is *increasing*, then the information gained is *decreasing*. This is because ECD decreased the probability of a signal being of non-interest vice one of interest. For the SIGINT analyst, an increase in $p_0 + p_1$ and a decrease in p_2 is the desired situation. Within a specific region, the amount of area where there are no signals (p_0) means there is less area to evaluate and a greater chance that a known signal is one of interest.

In this scenario, forty percent of the map does not contain a known signal. This eliminated SNOIs and increased the probability of an SOI to two percent, with the remaining fifty-eight percent being SNOIs. The probability of desired outcomes before ECD ($p_0 + p_1$) and after ECD ($p'_0 + p'_1$) went from less than one percent to approximately forty-two percent. Overall, the information gained decreased because the uncertainty in the environment increased, but the uncertainty of an SNOI also decreased, which is a desired objective of ECD.

b. Sparsely Populated Region

Now consider a sparsely populated geographical area, a small village in the middle of a barren region. Now consider the minuscule amount of signals in this region (compared to a major city). A snapshot in time of the EM environment in this scenario is not as difficult for a SIGINT analyst to tackle as in the previous example. However, a SIGINT analyst must consider all locations where an SOI could appear. The faster an analyst can filter through a region of this nature, than the faster that analyst can undertake areas of dense population.

In this setting, there is a seventy percent chance that there is not a signal in a particular area, $p_0 = 0.7$. Now consider the probabilities of SOIs versus SNOIs. It is assumed that a thinly populated area of interest will have few SOIs as compared to

[8] All values of p_i and p'_i in both scenarios are arbitrary and based purely on the author's experience with a few ECD final products. The values will vary based on geographic region and situation; however, the relationship between the probabilities will be similar. This is important because quantifying the information gained depends heavily on both geographic region and situation.

SNOIs; but not as few as a major city. The probability of an SOI is set at five percent, or $p_1 = 0.05$ generating $p_2 = 0.25$ since the $p_0 + p_1 + p_2 = 1$.

After running ECD on this geographic area, the result is an even less cluttered snapshot of the EM environment. Since ECD eliminates the redundant signals, the value of p'_0 will again increase. As before, this increase will yield a slight increase in p'_1 also because the redundant signals tend to be SNOIs vice SOIs. Taking the following values of p'_i:

$$p'_0 = 0.85$$
$$p'_1 = 0.055$$
$$p'_2 = 0.095$$

Inserting these values into equation (4.3) produces I(x) = (0.32)*C.

These results are more intuitive than the previous example due to the positive value of information gained. Given that, the overall uncertainty is *decreasing*, then the information gained is *increasing*; opposite of the previous scenario. Just like before, the amount of area where there are no signals (p_0) means there is less area to evaluate and a greater chance that a known signal is one of interest in a specific region.

In this scenario, eighty-five percent of that region does not contain a known signal. This eliminated SNOIs and increased the probability of an SOI by only one-half of a percent. The probability of desired outcomes before ECD (p_0 + p_1) and after ECD (p'_0 + p'_1) went from seventy-five percent to just over ninety percent. Overall, the information gained increased because the uncertainty in the environment decreased, *and* the uncertainty of an SNOI also decreased, which once more is a desired objective of the ECD application.

4. Summary

Applying ECD to a given region can be compared to conducting an aerial reconnaissance over land targets. Quantifying the amount of information gained based on the level of uncertainty shows an increase in the summation of the probability of no signal and the probability of an SOI. A negative or positive value, based on scenario, will determine the level of increase of information. This quantified value will change based on geographic location, situation, and mission to be accomplished. Of importance is the relative decrease in the probability of an SNOI.

C. TIME GAINED BASED ON UNCERTAINTY

1. Overview

Determining the level of uncertainty is a necessary step to understanding the EM environment within a given region. A SIGINT analyst requires a certain amount of time to analyze a given geographic region in order to fully understand the EM environment. Understanding this environment well will aid commanders in making decisions to accomplish their mission. This analysis consumes a certain amount of the analyst's time. As seen in the previous section, a reduction in uncertainty leads to an increase in the amount of information provided. This section calculates how this same reduction in uncertainty will condense the amount of time necessary to locate an SOI.

2. Scenario

As a SIGINT analyst begins analyzing a new region, the level of uncertainty is high. Over time, that level of uncertainty decreases to an acceptable level. Determining what defines an acceptable level is situational dependent. Assumed in this analysis is a linear relationship between the level of uncertainty and time spent on analysis. The slope of this line is dependent on various characteristics to include the analyst's expertise, operational environment, and mission.

The following chart represents a scenario where there is initially a very high level of uncertainty in the EM environment. Over time, the analyst filters out the unnecessary information to point where he/she is comfortable with the operating environment. This level of uncertainty is assumed to be 0.1, or ten percent and is indicated by a green dashed line in the chart.

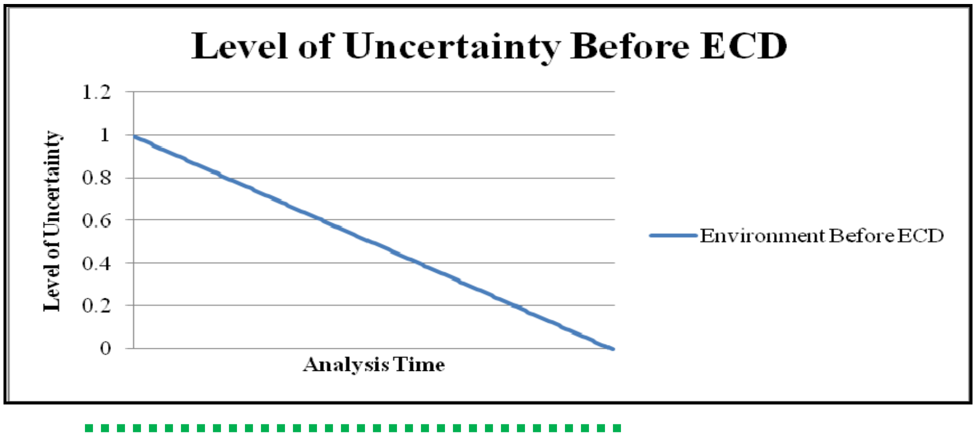

Figure 27. Environmental Uncertainty Prior to ECD.

Running ECD will alleviate a percentage of (redundant) signals in the operating environment. Eliminating these signals leads to an overall lower initial level of uncertainty in that environment. It is important to note that there are no claims being made that ECD will speed up a SIGINT analyst's ability to analyze a given environment. This is visually depicted in the equal slopes of the lines on the charts. What is simply being stated is that the initial conditions of that operating environment are altered due to ECD by decreasing the level of uncertainty in that region, as shown in Figure 28.

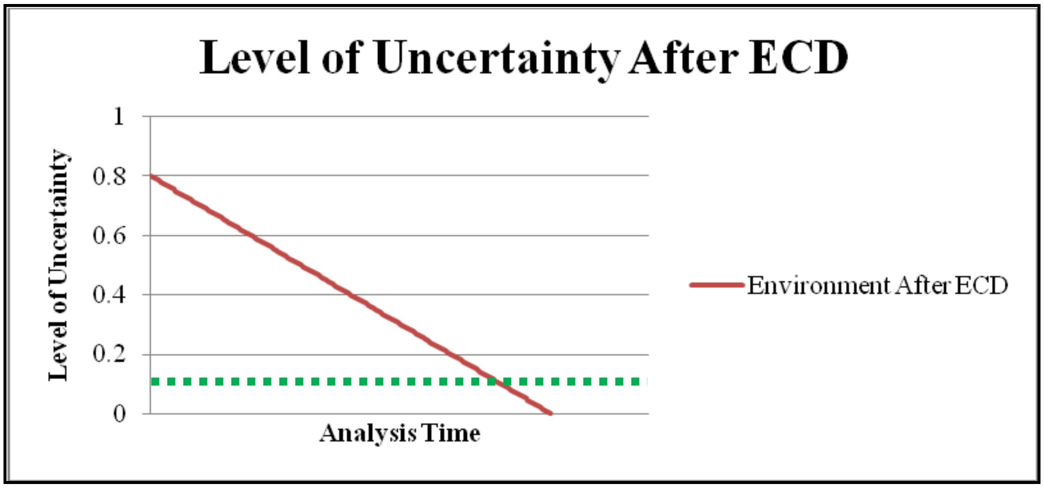

Figure 28. Environmental Uncertainty After to ECD.

Overlaying the two charts shows that the slopes remain constant. The only difference is the starting baseline for the analysis of that environment. Like the previous two charts, the green dashed line represents the minimum acceptable amount of uncertainty for a given region.

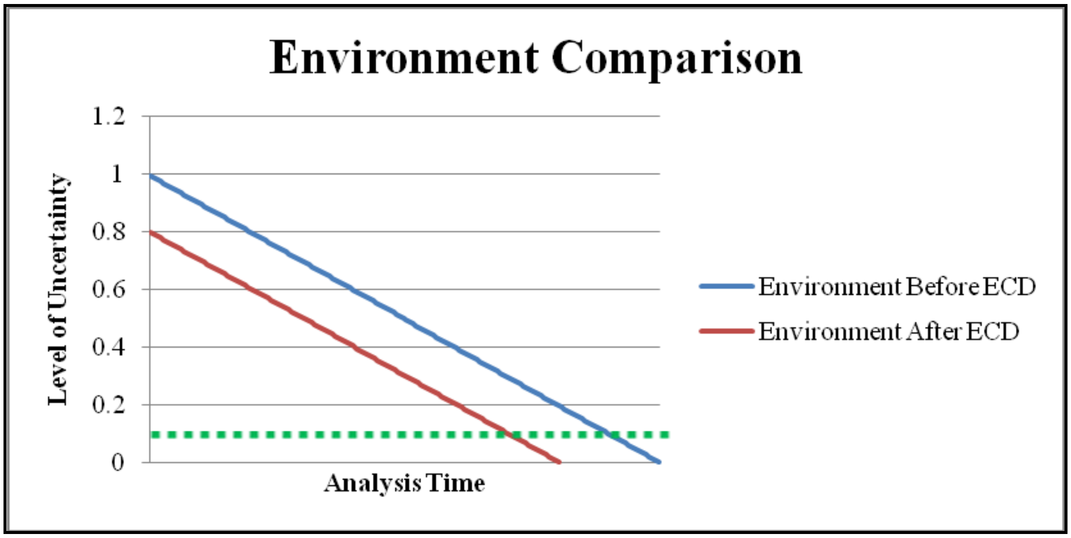

Figure 29. Environment Comparison Before and After ECD.

3. Summary

One can see that with the application of ECD, less time is required to analyze a given environment. The Δt, or change in analysis time, is dependent on the decrease in the level of uncertainty and slope of the analyst's uncertain line. An important assumption to validate the previous statement is the linear relationship between uncertainty and analysis time. Decreasing this time interval is paramount to the quicker completion of a commander's OODA loop.

D. VISUAL REPRESENTATION OF INFORMATION PROVIDED TO THE TACTICAL COMMANDER

This section is located in a classified appendix.

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V. CONCLUSIONS AND RECOMMENDED FUTURE WORK

A. CONCLUSIONS

SIGINT analysts are constantly overwhelmed by the amount of data they ingest and ECD was fashioned in order to alleviate a portion of the “background noise,” or signals of non-interest. ECD has been tested and its operational capability verified and validated by senior analysts. With the current organizational structure within which ECD resides, its utility to the tactical user is limited. This limitation affects both the timeliness of intelligence production and volume of users it can accommodate. An analytical model was devised to determine the sources of latency in response to a request for information (RFI). Various obstacles are highlighted and a revised operating procedure was modeled.

This thesis analyzes four aspects of an organization (task, technology, structure, and actors) and proposes a change in ECD implementation to affect the production of tactical intelligence. The intent of the revision, along with providing ECD to a tactical intelligence cell, is to allow the tactical commander to make more effective decisions with respect to the employment and deployment of forces, types of forces (kinetic versus non-kinetic) to employ, and maximizing the efficiency of organic intelligence collection assets. The organizational revision, coupled with required analyst training, allows information to be pushed to a tactical intelligence cell and commander within a window of six hours from collection of the signal. This window allows for the production of actionable intelligence, increases the efficiency of SIGINT analysts, and potentially drives tactical operations.

In order to effectively enhance a tactical commander’s decision-making process, the OODA loop timeline must be condensed while provide the same, if not more, information. ECD is proven to increase the amount of information gained by decreasing the uncertainty of information within a given region. This decrease in uncertainty, with all other parameters being equal, decreases the amount of time required to understand the EM environment in a given scenario. As ECD positively affects uncertainty and timeliness, the tactical commander’s first two steps (observe and orient) in the OODA loop condense, allowing decisions to be made faster and actions to occur faster. Condensing the OODA loop enough will force an adversary to be reactive vice proactive to coalition operations.

B. TACTICAL APPLICATION

ECD has passed all initial experimentation, verification, and validation[9] and is currently operational on a small scale at a strategic operations center. The best way to test the effectiveness at the tactical level is to integrate ECD with a unit who has previous operational experience in support of OIF and/or OEF and will deploy in support of OIF and/or OEF in the near future. Personnel who have deployed both with and without ECD technology will measure the tactical usefulness and effectiveness.

The author has selected 1st Radio Battalion (1stRadBn) located at Camp Pendleton, California as the tactical unit with which to evaluate and assess the usefulness of ECD at the battalion level. This selection was based on:

1. The author's familiarity with the integration of a Radio Battalion in Marine Air Ground Task Force (MAGTF) operations.
2. The operational tempo of deployments in support of OIF by 1stRadBn.
3. The operational experience of 1stRadBn leadership and SIGINT analysts alike in support of OIF.
4. The geographic location of 1stRadBn with respect to the NPS.[10]

Personnel interviews were conducted with 1stRadBn in order to discuss with SIGINT experts the utility of this technology and its effects on battalion operations. The effects were viewed as positive. Ideally, ECD will be implemented in an upcoming deployment in support of OIF or OEF.

[9] Details of all experimentation, verification, and validation are classified.

[10] It is not the intent of the author to conclude that any bias has been given to 1stRadBn over the other Radio Battalions based on performance. For the purpose of thesis research, funding was allotted for travel within California, making 1stRadBn the optimal tactical unit to select.

1stRadBn and the author agreed to use a past operational significant event as a template for trend analysis. Analyzing the situation with ECD, including the events that led up to the significant event and possible tippers of its occurrence, will demonstrate a noteworthy capability ECD would provide to 1stRadBn. The true value of ECD will only be realized once provided to a tactical unit conducting real-world operations with a defined and distinct situation and mission.

C. RECOMMENDED FUTURE WORK

Several areas of future research and work have been identified throughout the creation of this thesis. They are:

- Derive an alternate evaluation method, involving conditional entropy, which is "entropy of a random variable, given another random variable" (Cover, 1991).
- Identify quantifiable evidence of proper decision-making based on ECD.
- Quantify the utility of ECD with respect to maximizing organic intelligence collection assets at the tactical level.
- Analyze the utility and information gained (cost-benefit analysis) of providing ECD on both JWICS and SIPRNet.
- Continue end-user collaboration with 1st Radio Battalion, USMC with the intent of:
    - Evaluating real-world operational tests (Pre- and Post-ECD).
    - Reassessing best/most-practical implementation practices.
    - Continuing revision of operating procedures from lessons learned via operational testing.
    - Outlining and implementing an ECD application training plan.
- Analyze the effect of ECD at the MAGTF Commander level with implementation at a Radio Battalion.

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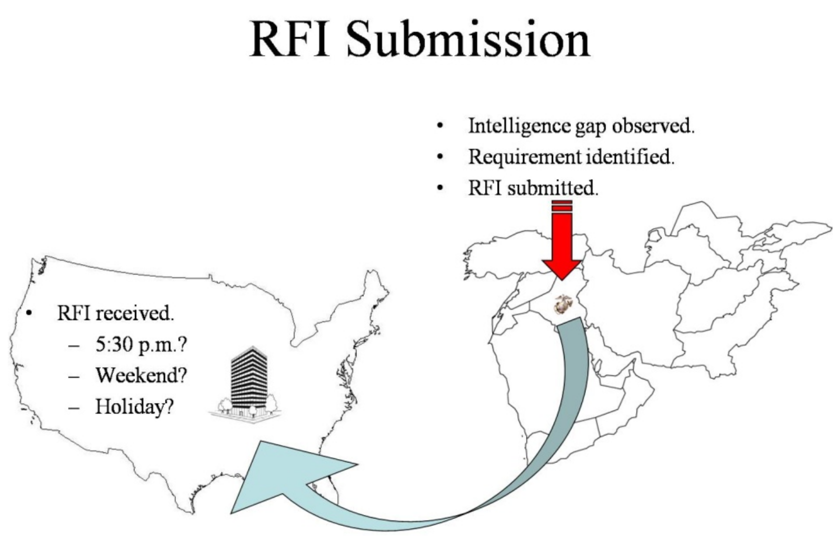
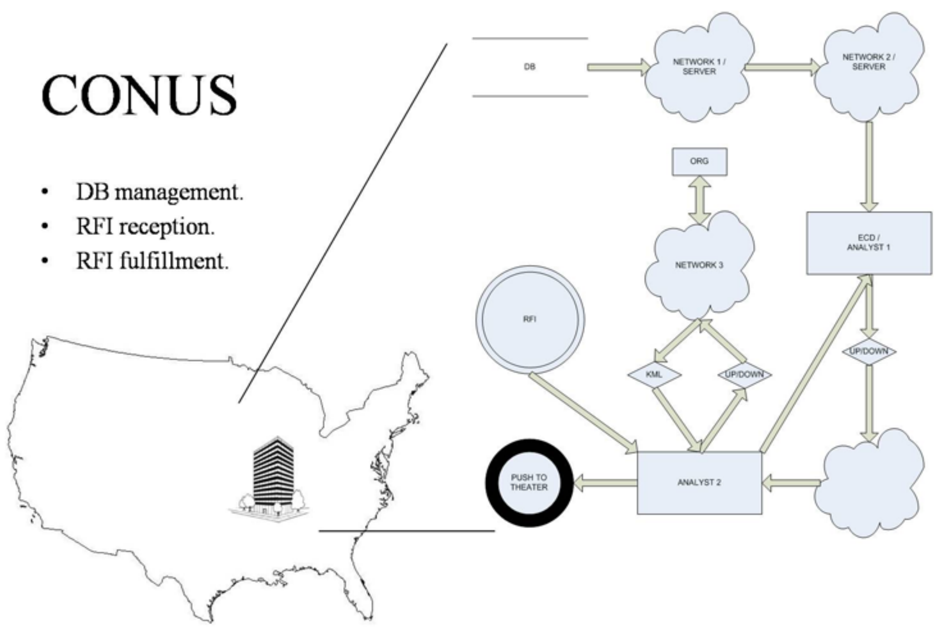
APPENDIX A. CURRENT PROCESS DIAGRAM

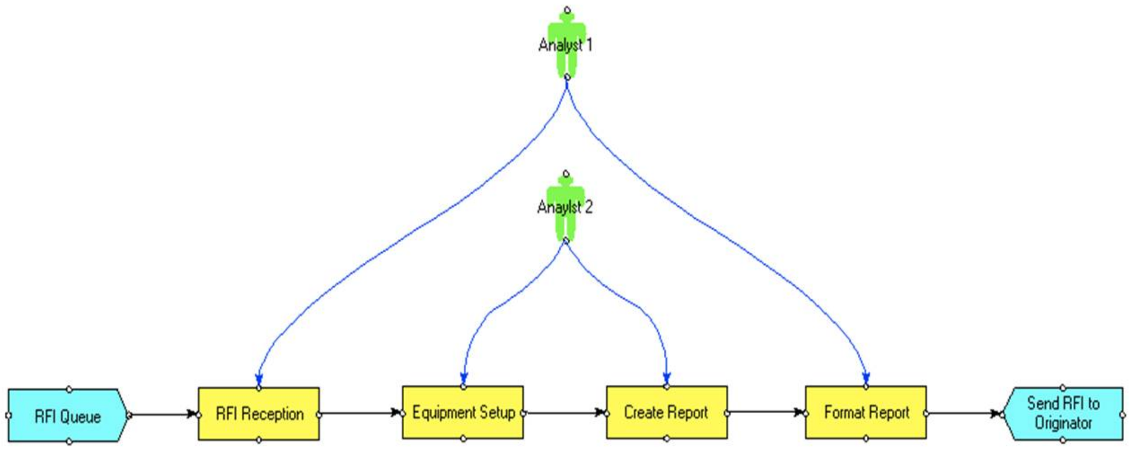
The following is a typical path in the RFI submittal process. The process begins with the observation of an intelligence gap.



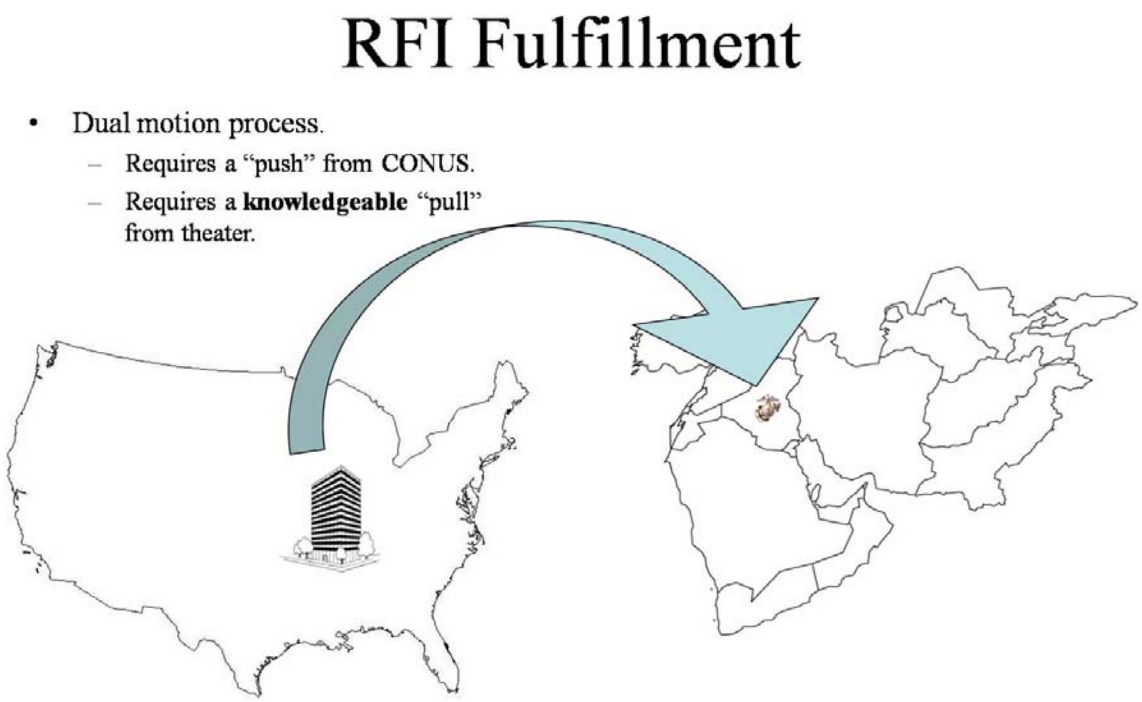
Once the RFI reaches the U.S. (CONUS), it is placed in a queue and resides there until an analyst begins to process the RFI. The next diagram is characteristic of the information flow between analysts.



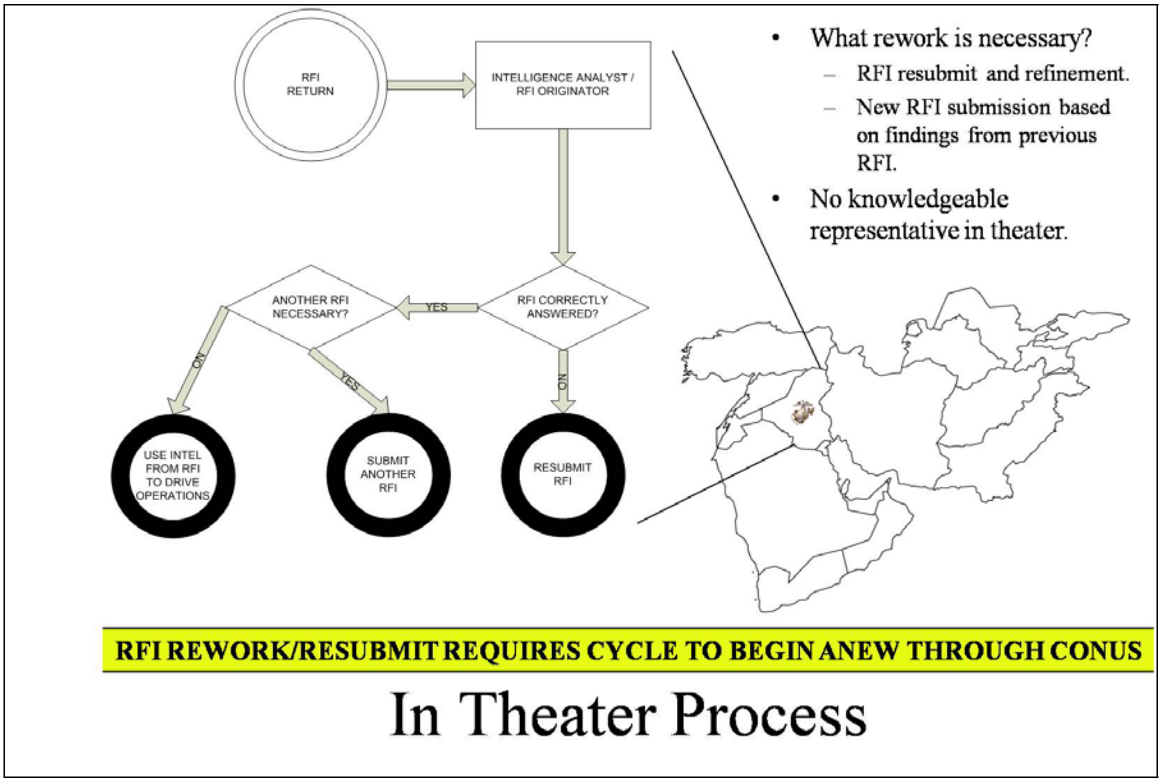
A simplistic visualization of this process is as follows.



Once the finalized report is properly formatted, the RFI is sent back to its originator.



The rest of the process resides in the theater of operations. At this time in the process, it is necessary to consider what rework (if any) is required.


RFI RETURN
INTELLIGENCE ANALYST / RFI ORIGINATOR
RFI CORRECTLY ANSWERED?
YES
ANOTHER RFI NECESSARY?
NO
YES
NO
USE INTEL FROM RFI TO DRIVE OPERATIONS
SUBMIT ANOTHER RFI
RESUBMIT RFI
• What rework is necessary?
– RFI resubmit and refinement.
– New RFI submission based on findings from previous RFI.
• No knowledgeable representative in theater.
RFI REWORK/RESUBMIT REQUIRES CYCLE TO BEGIN ANEW THROUGH CONUS
In Theater Process

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APPENDIX B. CURRENT PROCESS HOURLY PROBABILITY

RFI Submittal Reference (7am - 5pm)	Actual Time Latency (Hrs)	Frequency of Occurrence (Hrs per week)	Probability of Occurrence: P(X)	Expected Value: E(X)	Population Variance: V(X)	NORMALIZED
work day	0 - 1	55	0.327380952	0.327381	58.9831465	0.017049084
5am (Mon)	1 - 2	5	0.029761905	0.0595238	4.59290071	0.017797419
4am	2 - 3	5	0.029761905	0.0892857	3.88322101	0.018516944
3am	3 - 4	5	0.029761905	0.1190476	3.23306511	0.019201623
2am	4 - 5	5	0.029761905	0.1488095	2.64243303	0.019845538
1am	5 - 6	5	0.029761905	0.1785714	2.11132475	0.020442979
midnight	6- 7	5	0.029761905	0.2083333	1.63974028	0.020988519
11pm	7 - 8	5	0.029761905	0.2380952	1.22767963	0.021477106
10pm	8 - 9	5	0.029761905	0.2678571	0.87514278	0.021904132
9pm	9 - 10	5	0.029761905	0.297619	0.58212974	0.022265511
8pm	10 - 11	5	0.029761905	0.327381	0.34864051	0.022557742
7pm	11 - 12	5	0.029761905	0.3571429	0.17467509	0.022777964
6pm	12 - 13	5	0.029761905	0.3869048	0.06023348	0.022924007
5pm	13 - 14	5	0.029761905	0.4166667	0.00531568	0.022994421
4pm (start pure Sun)	14 - 15	1	0.005952381	0.0892857	0.00198434	0.022988507
3pm	15 - 16	1	0.005952381	0.0952381	0.0148103	0.022906324
2pm	16 - 17	1	0.005952381	0.1011905	0.03954103	0.022748688
1pm	17 - 18	1	0.005952381	0.1071429	0.07617651	0.022517161
noon	18 - 19	1	0.005952381	0.1130952	0.12471676	0.022214025
11am	19 - 20	1	0.005952381	0.1190476	0.18516178	0.021842242
10am	20 - 21	1	0.005952381	0.125	0.25751155	0.021405407
9am	21 - 22	1	0.005952381	0.1309524	0.34176608	0.020907693
8am	22 - 23	1	0.005952381	0.1369048	0.43792538	0.02035378
7am	23 - 24	1	0.005952381	0.1428571	0.54598944	0.019748784
6am	24 - 25	1	0.005952381	0.1488095	0.66595826	0.019098179
5am	25 - 26	1	0.005952381	0.1547619	0.79783184	0.018407717
4am	26 - 27	1	0.005952381	0.1607143	0.94161019	0.017683336
3am	27 - 28	1	0.005952381	0.1666667	1.09729329	0.016931086
2am	28 - 29	1	0.005952381	0.172619	1.26488116	0.016157039
1am	29 - 30	1	0.005952381	0.1785714	1.44437379	0.015367211
midnight (Sat/Sun)	30 - 31	1	0.005952381	0.1845238	1.63577119	0.014567488
11pm (Sat)	31 - 32	1	0.005952381	0.1904762	1.83907334	0.013763555
10pm	32 - 33	1	0.005952381	0.1964286	2.05428026	0.012960833
9pm	33 - 34	1	0.005952381	0.202381	2.28139193	0.012164423
8pm	34 - 35	1	0.005952381	0.2083333	2.52040837	0.011379062
7pm	35 - 36	1	0.005952381	0.2142857	2.77132958	0.010609081
6pm	36 - 37	1	0.005952381	0.2202381	3.03415554	0.009858376
5pm	37 - 38	1	0.005952381	0.2261905	3.30888627	0.00913039
4pm	38 - 39	1	0.005952381	0.2321429	3.59552175	0.008428099

3pm	39 - 40	1	0.005952381	0.2380952	3.894062	0.007754008
2pm	40 - 41	1	0.005952381	0.2440476	4.20450701	0.007110157
1pm----------	41 - 42	1	0.005952381	0.25	4.52685679	0.006498131
noon	42 - 43	1	0.005952381	0.2559524	4.86111132	0.005919078
11am	43 - 44	1	0.005952381	0.2619048	5.20727062	0.005373732
10am	44 - 45	1	0.005952381	0.2678571	5.56533468	0.00486244
9am	45 - 46	1	0.005952381	0.2738095	5.9353035	0.004385195
8am	46 - 47	1	0.005952381	0.2797619	6.31717708	0.003941666
7am	47 - 48	1	0.005952381	0.2857143	6.71095543	0.003531239
6am	48 - 49	1	0.005952381	0.2916667	7.11663853	0.003153049
5am	49 - 50	1	0.005952381	0.297619	7.5342264	0.00280602
4am	50 - 51	1	0.005952381	0.3035714	7.96371903	0.002488897
3am	51 - 52	1	0.005952381	0.3095238	8.40511642	0.002200288
2am	52 - 53	1	0.005952381	0.3154762	8.85841858	0.001938691
1am	53 - 54	1	0.005952381	0.3214286	9.32362549	0.001702526
midnight (Fri/Sat)	54 - 55	1	0.005952381	0.327381	9.80073717	0.001490169
11pm (Fri)	55 - 56	1	0.005952381	0.3333333	10.2897536	0.00129997
10pm	56 - 57	1	0.005952381	0.3392857	10.7906748	0.001130284
9pm	57 - 58	1	0.005952381	0.3452381	11.3035008	0.000979486
8pm	58 - 59	1	0.005952381	0.3511905	11.8282315	0.00084599
7pm	59 - 60	1	0.005952381	0.3571429	12.364867	0.000728263
6pm	60 - 61	1	0.005952381	0.3630952	12.9134072	0.000624839
5pm	61 - 62	1	0.005952381	0.3690476	13.4738523	0.000534323
		168		**14.42262**	**300.82735**	
			Standard Deviation =		**17.344375**	**hrs**
			=		**17 hrs 21**	**mins**

APPENDIX C. SENIOR EXECUTIVE PRESENTATION

Captain Derek Filipe, USMC

- B.S. Mechanical Engineering, The George Washington University, 2003
- Pursuing:
  - M.S. in Systems Technology
  - M.S. in Space Systems Operations
- OPERATION: ENDURING FREEDOM
  - Intelligence Officer, HMH-462
  - Sep 2004 - Mar 2005
- OPERATION: IRAQI FREEDOM
  - Intelligence Advisor, Iraqi Border Patrol
  - Apr 2006 - Apr 2007

FOCUS AREAS

- Organizational Analysis
- Command & Control Analysis
- Tactical Dissemination Analysis

METHODS

- Quantitative Analysis
- End-User Collaboration
- Personnel Interviews
- Operational Testing

ENDSTATE: OPTIMIZATION OF INFORMATION FLOW TO TACTICAL LEVEL

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Energy Change Detection

If Energy Change Detection (ECD) is provided to a tactical intelligence cell with a revised operating procedure, then the potential for more effective decision-making by the tactical commander exists, allowing said commander to make more informed decisions on:

- Employment and deployment of forces.
- Which type (kinetic versus non-kinetic effects) of forces to employ.
- How to maximize the utilization of organic intelligence collection assets.

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Approach

• Work with the analysts to be able to effectively model the current employment of ECD.

• Identify pitfalls and sources of latency in the current model.

• Propose a new operating procedure for ECD.
  – Implement and test.

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Current ECD Process

- Process initiated once RFI submitted.
  - Observation of an intelligence gap.
  - Requirement identified.
  - "Push-and-Pull" system.
- Large disparity in time interval once RFI submitted.
  - Dependent on CONUS workday.
- End User not familiar with process.
  - Does not know what to ask for.
  - Does not fully understand the capabilities.
  - Cannot submit RFI until the requirement exists.

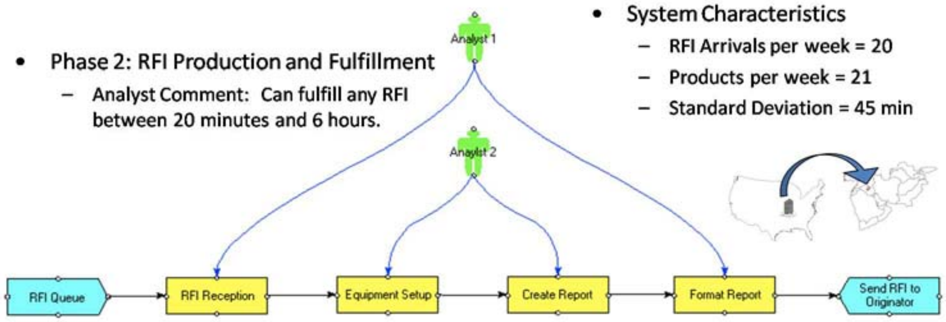
UNCLASS//FOUO

Current Process

- Phase 1: RFI Submittal
  - Intelligence gap observed.
  - Requirement identified.
  - RFI submitted.

- Phase 2: RFI Production and Fulfillment
  - Analyst Comment: Can fulfill any RFI between 20 minutes and 6 hours.

- System Characteristics
  - RFI Arrivals per week = 20
  - Products per week = 21
  - Standard Deviation = 45 min



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Queuing Calculations

Characteristics of (M/G/1) System	Current Process
Average number of RFIs received per week (Based on Historical Data).	20
Maximum service rate (Number of RFIs per week).	21
Percent utilization.	95
Number of RFIs in the queue.	9.1
Number of RFIs in the system.	10
Average time spent waiting in the queue per RFI (days).	**3.2**
Average time spent in the system per RFI (days).	**3.5**
Percentage that there are no RFIs in the system.	5

Not Tactically Acceptable.

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Current Problem Areas

- Potential sources of latency.

  1. Information versus intelligence.
  2. “Pushing” vs. “Pulling” information.
  3. Bottleneck.
  4. Human-in-the-loop.
  5. Clearance and access.

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Proposed Solution

- ECD on SIPR.
  - SI/TK versus functionality.
- KMLs “pushed” to all users.
  - Geo-Filtered reports.
  - 4 hour time intervals, tactically acceptable.
  - Historic reports useful for trend analysis.
- Eliminates the RFI submittal process.
  - Instant access upon requirement realization.
- Removal of the Human-in-the-loop.
  - Human needed for analysis, not information push.

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Preliminary Conclusions

- Time to fully implement this technology.
  - **Ready for Full Operational Capability.**
  - Clear and present utility at the tactical level.
  - High potential to drive operations.

- Reside on either SI/TK system and/or SIPRNET.
  - Pros and Cons analysis of residing on both.
  - Database storage concerns require analysis.

- End User familiarization necessary.

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Way Forward

- Technology implementation.
  - Collaboration with Mr. John Abe.
  - Database familiarization.

- End User collaboration.
  - 1st Radio Battalion, USMC.
    - Camp Pendleton, CA.
  - Potential for real-world operational testing.
  - Reassessment of best/most-practical implementation.
    - After Action Reports / Lessons Learned.
  - Revision of operating procedures.

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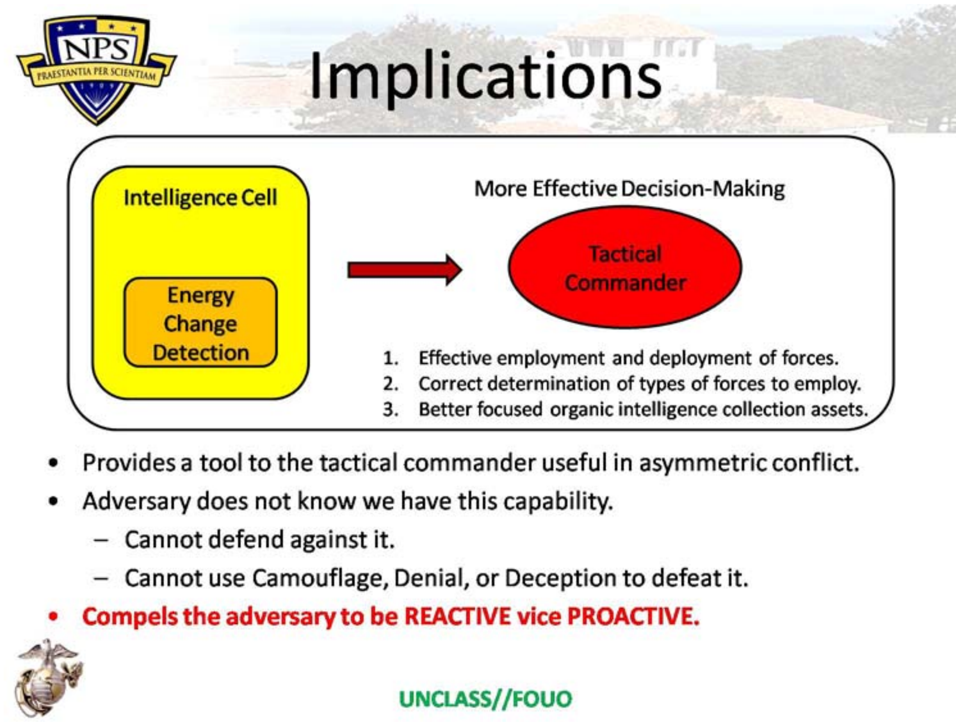

Implications
Intelligence Cell
Energy Change Detection
More Effective Decision-Making
Tactical Commander
1. Effective employment and deployment of forces.
2. Correct determination of types of forces to employ.
3. Better focused organic intelligence collection assets.
• Provides a tool to the tactical commander useful in asymmetric conflict.
• Adversary does not know we have this capability.
– Cannot defend against it.
– Cannot use Camouflage, Denial, or Deception to defeat it.
• Compels the adversary to be REACTIVE vice PROACTIVE.
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APPENDIX D. SCENARIO CALCULATIONS AND FORMULAS

I(x) = Information gained concerning a particular region
x = Amount of effort devoted to that region
(x is constant with respect to ECD)

There is uncertainty associated with each signal.

P0 = There is no signal
P1 = Signal of Interest (SOI)
P2 = Signal Not of Interest (SNOI)
P0+P1+P2 = 1

Uncertainty for 1 region: U(P0,P1,P2) = -c[SUM(Pi log Pi)]

Uncertainty as a result of ECD: U(P'0, P'1, P'2) = -c[SUM(P'i log P'i)]

The information produced by ECD:

I(x) = U(P0,P1,P2) - U(P'0, P'1, P'2)

SCENARIO 1: DENSELY POPULATED REGION

P0 = 0	P'0 = 0.4
P1 = 0.005	P'1 = 0.01
P2 = 0.995	P'2 = 0.59

U(P0,P1,P2) = 0.045414692c
U(P'0, P'1, P'2) = 1.044325553c

I(x) = -0.998911c

SCENARIO 2: SPARSELY POPULATED REGION

P0 = 0.7	P'0 = 0.85
P1 = 0.05	P'1 = 0.055
P2 = 0.25	P'2 = 0.095

U(P0,P1,P2) = 1.076297626c
U(P'0, P'1, P'2) = 0.752052041c

I(x) = 0.3242456c

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